CRITICAL EVALUATION OF THE NUMERICAL DESIGN FOR THE METAL ROOF OF A SHOPPING CENTER

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ABSTRACT

This study focuses on evaluating the project phase related to the investigation of stages and construction processes for the development's steel-structured roof. To reach this final stage, comprehensive studies were conducted on the designated construction site, including an examination of technical standards and relevant legislation governing building development. The shopping center, occupying a 6,480m² plot with a built-up area of 2,593m², encompasses commercial stores, a food court, restrooms, communal spaces, a bowling alley, circulation areas, and external parking. The design process utilized the Cype3D program (2017), employing stiffened U-type profiles for both purlins and truss bars in the optimized version. All design specifications were carefully considered to achieve optimal results in profile selection. It is important to note that a critical analysis, through additional checks, was performed to validate the effectiveness of the numerical simulation in comparison with manual design, adhering to the criteria outlined in NBR 8800 (ABNT, 2008).

KEYWORDS: *Commercial center; Coverage; Design; Numerical simulation; Metal truss.*

I. INTRODUCTION

With the population of the city of Divinópolis/MG reaching approximately 242,505 inhabitants in 2021, as projected by the Municipal Institute of Geography and Statistics (IBGE, [1]), and significant socio-economic development occurring in the southeast and southwest regions of the municipality due to the establishment of the Administrative Center of Divinópolis (Municipal Government) and universities, as well as the expansion of commerce and residential properties, the construction of the commercial center is based on the proposal of a large-scale retail establishment. This center will offer a diverse range of products for consumers, accompanied by the provision of services and leisure activities to meet the demands of the local population.

The building is situated on an area of 6,480 m². In accordance with Land Use and Occupation Law No. 2.418, dated November 18, 1998 (Divinópolis, [2]), and in compliance with municipal laws, an assessment of physical and natural conditions has been carried out to meet the required parameters. This results in an occupancy area of 2,572 m² with a land occupancy rate of 39.7%. The studied development comprises two floors and is located between Lagoa da Prata Street, José da Silva Street, Wanyr Notini Pereira Street, and Amim José Barreto Street (shown in Figure 01) at the average geographical coordinates of 20°08'21"S and 44°53'17"W, in the southwest region of the city. The main entrance of the Commercial Center is on Lagoa da Prata Street, a collector road with high pedestrian and vehicular traffic, while access to the parking area is provided via José da Silva Street, a local road.

To complete the development, 21 stores are distributed between the ground floor and the first floor, along with two common areas in the central part of each floor for circulation. Additionally, there is an indoor and outdoor food court, bathrooms on both floors, and a playground with bowling and a snack bar. Rest areas are provided on both floors, accommodating the specific needs of employees.

Figure 1. Location of the Commercial Center plot.
Source: Adapted by the authors from Google Earth – Image by Maxar Technologies (2022).

This work focuses on the conception and sizing stages of the metal roof in this project, conducted with the assistance of Cype3D software (2017). The decision to use steel as the structural material for the roof is attributed, among various advantages, to its rapid construction capabilities. A study by Ramadhan, Paramita & Srinivasan [3] illustrates that construction costs and project timelines are influenced by material decisions. The study emphasizes the crucial role of construction speed in the efficiency of the subject studied by these authors, specifically a Light Steel Frame house. It concludes that a construction speed of 4.19 m²/h, based on labor, could be an alternative for providing affordable housing and addressing construction delays for low-income individuals.

According to Pratti Júnior [4], achieving a good result in a construction project, regardless of the material used, requires comprehensive planning encompassing all stages and adherence to norms and concepts. In a case study by Pratti Júnior [4], it is suggested that discrepancies in safety factors and calculations may arise when profiles are oversized, potentially due to considerations beyond standard calculations, such as future use changes, expansions, or contractor-specific parameters not included in the original project. Considering the importance of selecting metal profiles, Mello [5] conducted a cost study for a metal roof structure, comparing the executed project on site. The study emphasizes the need to balance optimization with financial aspects, as increasing profile sections may reduce the structure's weight but could also burden the structure due to the high cost of raw materials and non-standardization of profiles. However, earlier studies have shown that the pronounced higher mode effect in these structural systems can result in an uneven deformation pattern. (Li & Wang [31]). Pillar's work [6] compares three structural solutions for the truss main beams of the large-span metal roof of the Ceará Events Center in Fortaleza/Brazil: hot-rolled profiles, cold-formed profiles, and tubular profiles. The study concludes that, based on market values, the solution with hot-rolled profiles has the highest total weight and significantly higher costs due to factors such as low-resistance steel, the necessity of welded connections, and corrosion protection.

Lima & Silva [7] technical-economic study focusses on a metal roof where sizing was done using high-strength steel. The study reveals a reduction in the total weight and cost (around 6%) with high-strength steels but notes that significant savings are limited due to the high cost associated with purchasing these metal profiles, especially in Brazil. Armed with these technical considerations, the text takes a standpoint regarding the initial conception of the subject in this work. The aim of this work is to elaborate, develop, and present the sizing stages for the metal roof of the Shopping Center, ensuring compliance with relevant standards, legislation, and construction processes for a commercial building in the city of Divinópolis/MG/Brazil.

This paper is organized into sections that comprehensively address various aspects of the study. The Introduction contextualizes the problem, highlights its relevance, and outlines the research objectives. The Materials and Methods section provides detailed calculations for verifying and specifying the structural profiles, along with an exploration of the research limitations. The Results and Discussion section presents the study's findings, examining the impact of geometric properties on the chosen metal profiles for the project. This section includes graphs, tables, and a thorough discussion of the design criteria for the metal roof structure. The conclusion succinctly summarizes the main results, discusses practical implications, offers recommendations based on the findings, and suggests avenues for future research.

II. MATERIALS AND METHODS

2.1. Description of the project

All areas of the development comply with the requirements of NBR 9050 (ABNT, [8]), ensuring accessibility, inclusion, and respect for a diverse range of customers and employees moving through the building. The external area of the main building remains uncovered, exempting it from being counted as part of the constructed area. This design choice allows for a more efficient use of the entire plot for an extensive parking lot, providing 62 car spaces, including 2 spaces for People with Disabilities (PNE) and 2 spaces for the elderly, along with motorcycle parking.

The building structure is constructed with reinforced concrete, and the slabs of both floors are solid, as large spans were not incorporated into the design. The roof is supported by a metal structure, and galvanized sheets serve as the roofing material. The central section of the roof utilizes polycarbonate material, enhancing the utilization of natural light. Figures 2 and 3 illustrate the longitudinal profile of section AA and the transverse profile of section BB, respectively. Figure 4 presents the 3D facade of the Commercial Center, rendered with the assistance of Lumiun3D software (version 2022).

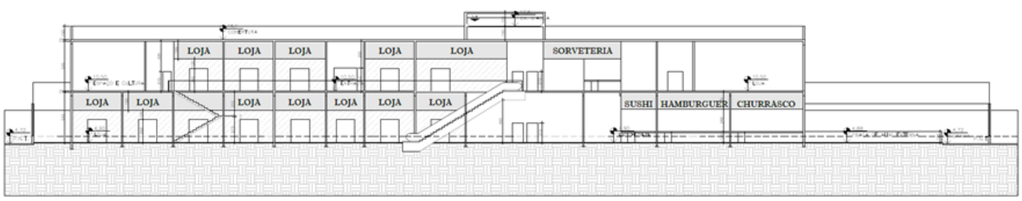

Figure 2. Section AA.

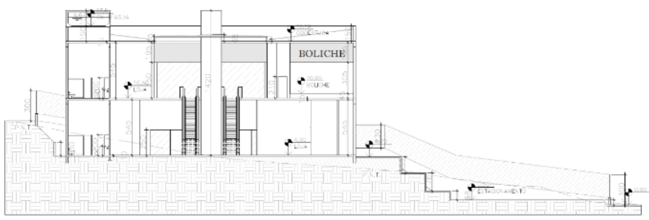

Figure 3. Section BB.

Figure 4. 3D Facade of the shopping center.

2.2. Normative conception

The entire development of the architectural project is grounded in the following municipal, state, and federal laws and standards:

- Law No. 2418/88 - Regulates Land Use and Occupation in the municipality of Divinópolis/Minas Gerais/Brazil – *In Portuguese*.
- Law No. 1071/73 - Establishes the Building Code of Divinópolis/Minas Gerais/Brazil – *In Portuguese*.
- Federal Law No. 10.098/00 - Establishes general norms and basic criteria for promoting accessibility for persons with disabilities or reduced mobility and provides other measures – *In Portuguese*.
- Federal Law No. 10.741/03 - Concerns the Statute of the Elderly and provides other measures – *In Portuguese*.
- ABNT NBR 6492/94 - Representation of architectural projects – *In Portuguese*.
- ABNT NBR 9050/20 - Accessibility to buildings, furniture, spaces, and urban equipment – *In Portuguese*.
- ABNT NBR 16636/17 - Preparation and development of specialized technical services for architectural and urban projects – *In Portuguese*.

2.3 Location and neighbourhood characterization

The Commercial Center development is in the Belvedere II neighbourhood, in the city of Divinópolis/MG/Brazil, in block 144, between Lagoa da Prata Street, Wanyr Notini Pereira Street, José da Silva de Oliveira Street, and Amim José Barreto Street.

In its vicinity, there are various urban facilities such as educational institutions (universities and schools), public services (city hall), churches, bakeries, bars, restaurants, and an exhibition park. Additionally, it benefits from satisfactory urban infrastructure, with most streets being asphalted, access to water supply, sanitary sewage, stormwater collection, solid waste collection, electricity, internet and telephone networks, and public transportation.

According to Municipal Law No. 2418, dated November 18, 1988 (Divinópolis, [2]), governing land use and occupation, the lot is situated in an R1 Zone (Residential Zone 1), and the designated use category is BC (Neighbourhood Commerce).

2.4 About the architectural project

The Commercial Center comprises a two-story building with a constructed area of 4,840m² and a ground occupancy of 2,270m², complying with the permitted limits stipulated by the land use and occupancy law (Divinópolis, [2]), falling within the 72% specified by the regulation. The building's height, front, and side setbacks meet the requirements set by Law No. 1071, dated November 21, 1973 (Divinópolis, [9]).

The main block features a spacious customer circulation area, reception, 21 stores, 6 snack bars, internal and external food court, ice cream parlor, playground, bowling alley, library, sanitary facilities, and general service areas. The external area includes parking, circulation areas, and landscaping. Constructed with reinforced concrete, the structure ensures durability and strength, with finishes in porcelain tiles and granite for sophisticated and long-lasting floors. Aluminium and glass frames offer excellent visibility to shop windows, while stainless steel (304) guardrails provide elegance and safety to stairs, ramps, and balconies.

The 21 stores range in size from 34m² to 330m², featuring a high ceiling of 5.60m, distributed between the 1st and 2nd floors. Six snack bars form a food court accommodating up to 246 people, with outdoor seating for a natural and fresh atmosphere during the afternoons. For leisure, the Space and Culture area provides a designated space for reading and relaxation, with a conceptual and modern ambiance. It serves as a place where children, youth, and adults can immerse themselves in literature, promoting reading among today's youth. Additionally, there's a designated playground for children's recreation and a bowling alley with four lanes, serving both as entertainment and a sport.

The project incorporates artificial lighting and ventilation systems, ensuring optimal visual and climatic conditions throughout the day. In this construction type, there is no mandatory requirement for openings for lighting and ventilation, as stated in Law No. 8.816, dated May 3, 2021 (Divinópolis, [10]). A notable architectural feature is the Zenithal lighting system, in the form of an Atrium, serving as the central roofing made of a metal structure and polycarbonate tiles with two slopes. This adds sophistication and modernity, allowing natural light during the day and reducing energy consumption. The facade is clad in contrasting porcelain tiles with a central detail in glass frames, bringing sophistication to the entrance, harmonized with elegant and concise landscaping. The main pedestrian entrance is on Lagoa de Prata Street, while a discreet entrance for loading and unloading is also provided.

2.5 Landscaping

Landscaping plays a crucial role in enhancing both the physical and mental well-being of individuals and the environment, fostering a harmonious blend of balance, health, and beauty. The natural surroundings contribute inexplicable feelings of peace and tranquillity [24]. It stands as a vital element in the overall design of a structure. To create a habitable space, landscaping is essential, serving to complement other factors such as the natural environment, buildings, and constructed structures.

The ground cover chosen is emerald grass, a popular choice in the region due to its widespread availability and versatility, allowing for year-round planting. Additionally, palm trees, Ipe, and Jacaranda have been selected for their ability to provide shade, create a cool environment, and bloom at different times throughout the year.

2.6 Accessibility

The accessibility of the shopping center aligns with NBR 9050 (ABNT, [8]) and the city's building code (Divinópolis, [9]). Stairs and ramps maintain a minimum width of 1.20m, with pedestrian slopes limited to 8.33% and vehicle slopes to 20%. Mirrors and floors are chosen based on the criteria outlined in Equation 1:

$$0{,}63\text{m} \leq p + 2e \leq 0{,}65\text{m} \quad (1)$$

The stair treads have been designed for comfort, featuring a 17cm rise and a 30cm tread. Access from the parking lot to the main building is facilitated by two staircases, each comprising 24 steps and boasting a width of 4.0 meters. Additionally, a zigzag ramp, inclined at 8.33%, has been incorporated to accommodate wheelchair users.

For vertical movement within the building, there are two sections of a U-type staircase connecting the first floor to the second. Each section consists of 34 steps, and the staircase has a width of 1.20 meters. In addition, two escalators, designated for upward and downward travel, provide an alternative means of access. Lastly, an elevator is available to facilitate wheelchair access to the second floor.

2.7 Computer modelling

In the design of the shopping center's roof, a metal structure was meticulously modeled to span distances and support the upper fence of the building. The use of U-type steel profiles and polycarbonate roof tiles was employed, adhering closely to the manufacturers' recommendations for fixings.

The structural system outlined here was developed with the assistance of Cype3d software (2017). This approach took into consideration the mechanical characteristics of the soil, the constraints and requirements of the architectural project described earlier, the planialtimetric survey of the construction site, and the environmental nuances specific to the region. It's essential to note that this project adheres to the prevailing Brazilian standards, especially:

- ABNT NBR 8800:2008 - Design of steel structures and steel-concrete composite structures for buildings (In Portuguese);
- ABNT NBR 6120:2019 - Loads for the Calculation of Building Structures (In Portuguese) [25];
- ABNT NBR 8681:2004 - Actions and safety in structures – procedure (In Portuguese) [26];
- ABNT NBR 6123:2013 - Forces due to wind in buildings – procedure (In Portuguese) [27].

Optimization methods using metaheuristic algorithms enhance traditional steel frame design, but their random search can lead to poor performance. This paper proposes combining metaheuristic algorithms with machine learning for a highly integrated method that includes online model training and parameter tuning. This improves optimization by reducing iterative impacts, enhancing convergence rate, and ensuring structural safety and economic benefits. Four cases demonstrate its effectiveness and generality, showing robustness and superior results in complex, large-scale problems (Shan *et al*. [30]).

III. RESULTS AND DISCUSSION

3.1 Roof metal structure

For the development, three roofs are dimensioned, as illustrated in Figure 5. These structures feature two waterfalls with a 5% slope and are constructed using A-36 steel profiles supplied by ArcelorMittal [11] in compliance with the recommendations of NBR 8800 (ABNT, [12]).

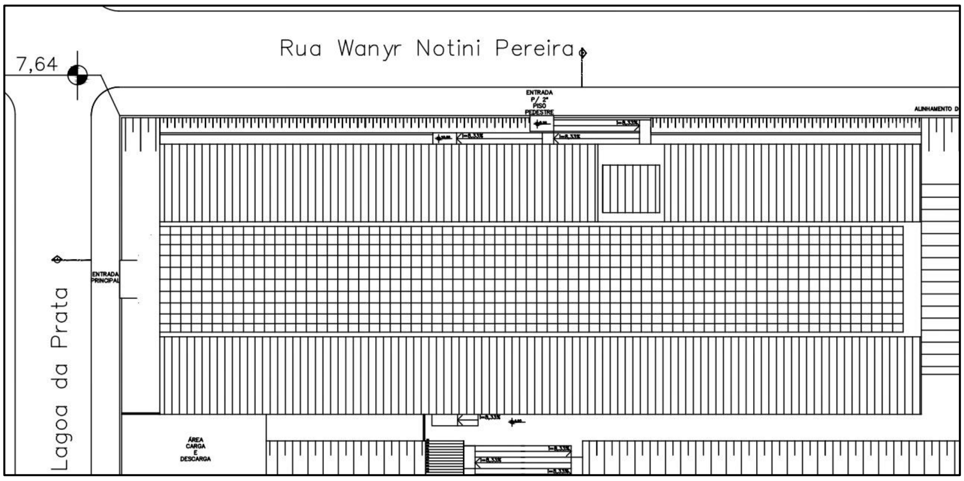

Figure 5. Development coverage.

The central structure, as modelled in the software, is depicted in Figures 6 and 7. Noteworthy is the inclusion of support for polycarbonate roof tiles with edge trim and vertical closure, designed to enhance natural lighting and incorporate landscaping elements. The span to be covered measures 11 x 46 meters, ensuring that the trusses efficiently transfer their loads directly onto the reinforced concrete structure's pillars. Although the distance between porticos does not adhere to a standard, it is consistently maintained below 5.7 meters, with an average spacing between spans of 4.94 meters. The lateral metal structure, as modelled in the software, is presented in Figures 8 and 9. Notably, attention is drawn to the support system for the galvanized steel roof tiles, designed primarily to ensure efficient rainwater runoff. The covered area comprises two rows measuring 8 x 80 meters, divided into 20 spans spaced 4 meters apart. This structure is securely fixed to the slab, directing water runoff towards the center of the building's roof.

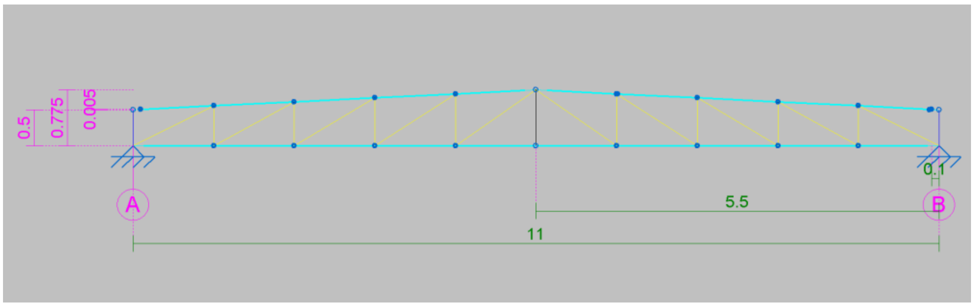

Figure 6. Detail of the central truss (in meters).

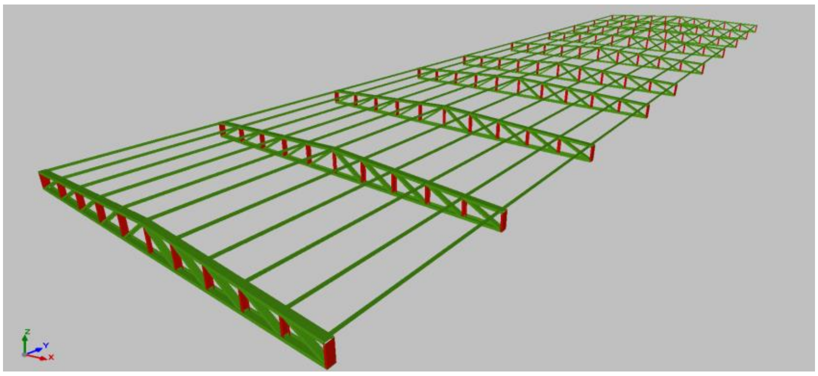

Figure 7. Central metal structure.

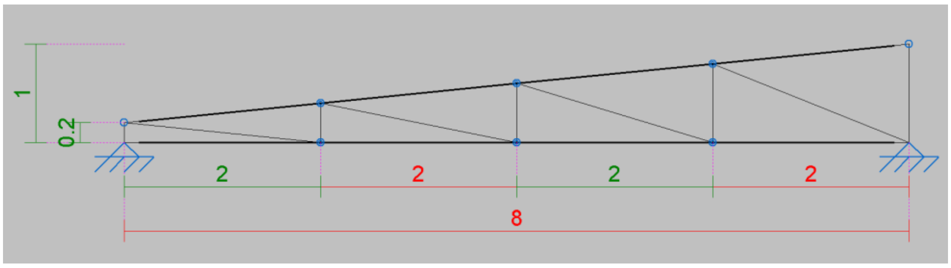

Figure 8. Detail of the side roof truss.

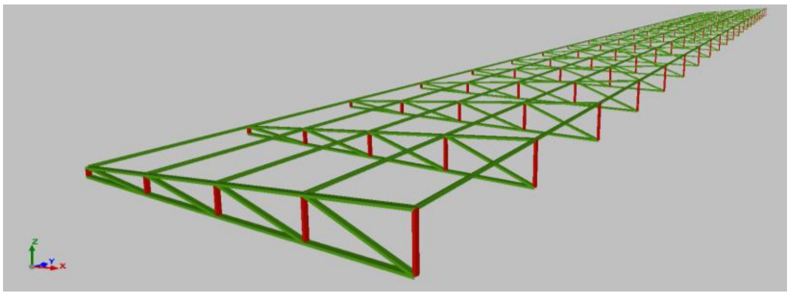

Figure 9. Metal structure of the side roof.

3.2 Loads

In addition to the standard loads outlined in Table 1, a point load of 1kN/m² has been considered for all roof structures to account for expected maintenance loads. These specified loads were input into the Cype3D software (2017). The central roof truss, with 11 nodes spaced 1.1 meters apart and distributed evenly, was analyzed using NBR 6120 (ABNT, [13]) to determine combinations of actions in the ultimate limit state (ULS).

Table 1. Determined loads

Load	Unit	Intensity
Own weight polycarbonate roof tile (ppp)	kN/m²	0.035
Galvanized steel tile own weight (ppa)	kN/m²	0.490
Normative overload (sn)	kN/m²	0.250
Maintenance overload (sm)	kN/m²	1.000
Dynamic wind pressure (pd)	kN/m²	0.740

To calculate dynamic pressure, it is essential to determine the parameters for the basic wind speed. These parameters, including the topographic factor, statistical factor, and characteristic speed, are determined in accordance with NBR 6123 (ABNT, [14]) standards. The VisualVentos software (Version 2.02) is employed for this purpose, considering a basic speed of 35m/s for the region, as depicted in Figure 1 of NBR 6123 (ABNT, [14]). The loads applied to each node are detailed in Table 2, accounting for the area of influence based on the distance between nodes.

Table 2. Node loads

Area of influence (m)	Load (as per Table 1)	Value (kN/m²)	Concentrated load on nodes (kN)	Combined loads (kN)
1.1 (in x-axis projection)	ppp	0.035	0.0385	0.5995
	sn	0.250	0.2750	
	sm	1.000	1.1000	
	pd	-0.740	-0.8140	

3.3 Execution

The assembly of all structural elements, including tiles, purlins, trusses, and other components used for joints and finishes, strictly adheres to the manufacturer's specifications. This meticulous approach ensures the correct functioning of the entire system [15-17].

3.4 Roof tile models adopted

The roof tile models adopted in this project comply with their resistive capacity, as recommended by the manufacturers. For the central structure, to fulfill its functions, compact polycarbonate tiles measuring 6m x 2.05m are used. Compact polycarbonate is very similar to tempered/laminated glass but has a combination of properties that make it much more resistant. According to Vick [17] these main characteristics are:

- Impact Resistance: Significantly surpassing glass by 250 times and acrylic by 30 to 40 times in resistance;
- Temperature Resistance: Maintains stability in temperatures ranging from -15°C to 120°C for continuous periods;
- Cold Bending: Exhibits flexibility with a minimum bending radius of 100 times the thickness of the sheet;
- Weight: Remarkably lighter than glass, with a weight that is only 50% of its counterpart;
- Anti-UV Protection: Offers protection against UV radiation, available on one or both sides of the sheet;
- Fire Safety: Does not propagate flames;
- Excellent Light Transmission.

For the side structures, 40mm x 0.43mm x 12m galvalume trapezoidal tiles are utilized, cut into 8m x 2m sections, made from galvanized steel [12].

3.5 Specification of Purlins

The purlins within the steel structure are designed using a stiffened U profile made of A-36 rolled steel, conforming to the sizing requirements outlined in NBR 8800 (ABNT, [11]) and the dimensions specified in the project. This choice aligns with recommendations found in the literature, including works by Pfeil & Pfeil [18] and Fakury, Castro e Silva & Caldas [19], which advocate for the widespread use of this profile for such structural elements.

In sizing the metal structure, consideration is given to technical characteristics based on the commercial reference TecnoMetal, with the local supplier ArcelorMittal being part of the TecnoMetal coverage group.To ensure optimal performance, the purlins are to be securely affixed perpendicular to the upper flange of the trusses. This installation method accommodates the roof tiles' angle of inclination, as specified in the project, achieved through a continuous weld bead. Profile Details:

- Central Roof: UDC Stiffened 100 x 50 x 17cm x 2.65mm (as computationally modeled in Figure 10).
- Side Roof: UDC Stiffened C75 x 40 x 15 x 2.00mm.

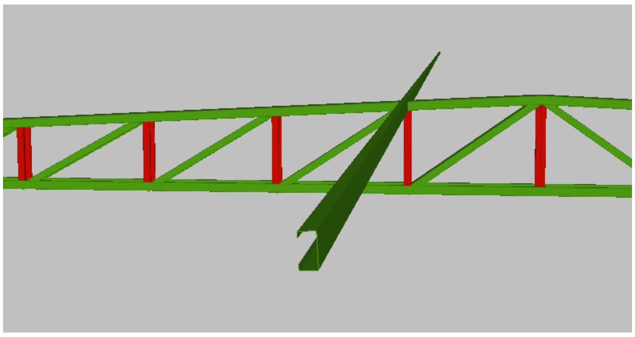

Figure 10. Computer model of Purlis

3.6 Standard Truss Profiles

The trusses consist of stiffened U profiles in A-36 steel, adhering to the specifications outlined in the Brazilian standard NBR 8800 (ABNT [11]), with dimensions as specified in the project. These design choices align not only with Brazilian standards but also find support in international references on steel structures, exemplified by works such as Galambos & Surovek [20] and Salmon, Johnson & Malhas [21]. In sizing the structure, technical characteristics were considered based on the commercial reference TecnoMetal, with the local supplier ArcelorMittal being part of the TecnoMetal group. Table 3 provides the names of the metal profile series for the truss bars. These designations are obtained directly from the software for the optimized version of the design situation, ensuring a safety convergence reliability given by the program of up to 98.7%.

Table 3. Designation of Profiles

Truss	Bar	Section
Central roof	Diagonals	UDC Stiffened 150 x 60 x 20cm x 3.04mm
	Upper and lower web	UDC Stiffened 200 x 75 x 25cm x 4.76mm
	Top	UDC Stiffened 75 x 40 x 15cm x 2.00mm
Side roof	Diagonals	UDC Stiffened 127 x 50 x 17cm x 3.42mm
	Upper and lower web	UDC Stiffened 125 x 50 x 17cm x 3.35mm
	Top	UDC Stiffened 100 x 50 x 17cm x 2.00mm

3.7 Maximum Vertical Displacement

Upon applying loads to the truss nodes and defining the profiles in the software, a thorough check is conducted to ensure they meet all safety criteria outlined in NBR 8800 (ABNT,[11]). Upon confirmation of the profiles' strength, the resulting truss displacement is determined to be 11.38mm for the central roof (refer to Figure 11) and 5.44mm for the side roofs.

In accordance with Table C.1 of NBR 8800 (ABNT,[11]), the structure must adhere to a maximum displacement limit specified by Equation 2 for combinations of actions in the Serviceability Limit State (SLS):

$$\delta = \frac{L}{180} \quad (2)$$

In which: δ is the displacement (in mm); L is the span width (in mm).

Therefore, comparing the maximum deflection values obtained with the assistance of the Cype3D software (2017) with the recommended maximum values, it is observed that they comply with the norm requirements. The specified limit for a span of 11 meters (central roof) is 61.11mm, and for 8 meters (side roof), it is 44.44mm. These results assume a safety convergence reliability provided by the program of up to 97.8%. According to Vaez *et al.* [29], achieving an optimal performance-based design (PBD) for a three-dimensional (3D) structure necessitates repeated evaluations. Therefore, proposed methods should aim to substantially decrease the number of evaluations needed during the optimization process. Additionally, Zeng *et al.* [28] simulated on 192 concentrically braced frames with H-section steel (Q355B) investigate low-cycle fatigue performance. Fatigue life ratio (β) reveals gusset plate-to-brace fatigue correlation, influenced by brace flange width-to-thickness ratio, connection coefficient, column-to-beam length ratio, and gusset plate slenderness. A probabilistic model predicts β, proposing a fatigue design method to enhance seismic capacity coordination.

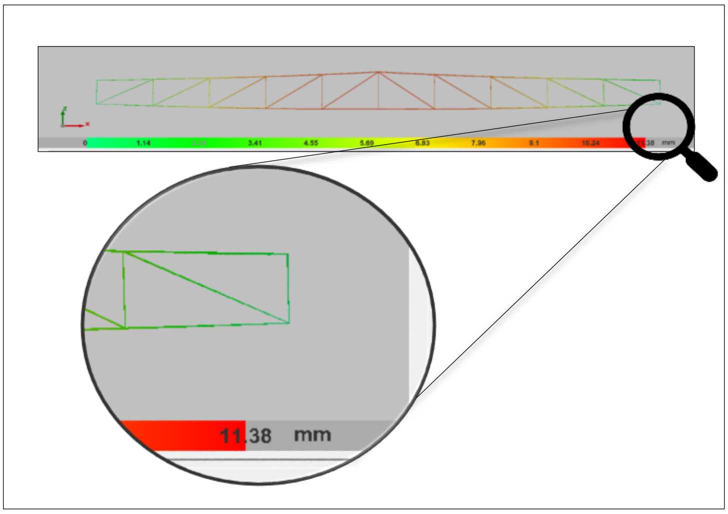

Figure 11. Maximum displacement.

3.8 Additional Verification

To validate the accuracy of the design obtained through the software and assess the variation between results, manual pre-dimensioning of the purlin was conducted following the standards. This supplementary check is advised by Pinheiro [23] in the context of computerized design. As per NBR 8800 (ABNT, [11]), the section height is determined by Equation 3:

$$\delta = \frac{L}{60} \quad (3)$$

In which: δ is the section height (in mm); and L is the span width (in mm).

Therefore, δ = 95 mm.

In section 4.7.7.2.1 of NBR 8800 (ABNT, [11]), Equation 4 is defined for calculating ultimate normal action combinations.

$$F_d = \sum_{i=1}^{m} \left(\gamma_{gi} F_{gi,k}\right) + \gamma_{q1} + \sum_{j=2}^{n} (\gamma_{qj} \psi_{0j} F_{Qj,k}) \quad (4)$$

Where: $F_{gi,k}$ represents values characteristic of permanent actions; $F_{Q1,k}$ is the characteristic value of the variable action considered as the main combination; $F_{Qj,k}$ represents the characteristic values of the variable actions that can act concurrently with the main variable action.

The values for the variables are determined using Table 1 and Table 2 of NBR 8800 (ABNT, [11]), coupled with the application of load values outlined in Table 2. This yields a result for the combination of actions, considering the hypothesis of self-weight + overloads + wind action, equal to 2.95 kN.

Following the preliminary sizing, the value of Ix is calculated, which is associated with the moment of inertia to determine the profile to be utilized. Ix is determined by computing the deflection displacement limit, which must be less than one hundred and eightieth of the span value according to NBR 8800 (ABNT, [11]). Therefore, Equation 5 is expressed as follows:

$$I_x \geq \frac{900qL^3}{384E} \quad (5)$$

Where: I_x is the moment of inertia of the profile (in cm^4); q is the value of the action combination (in kN/cm); L is the span width (in centimeters); and E is the modulus of elasticity of the material (in kN/cm^2).

Therefore, $I_x \geq 84{,}69\ cm^4$.

In this way, based on information obtained from the supplier's catalog, ArcelorMittal [12], as demonstrated in Table 4, it is possible to select the appropriate profile and confirm the results obtained through the Cype3D software (2017), which leads to the choice of the same stiffened U-profile with A-36 steel for this design situation.

Table 4. Selection of the profile according to the design stages of NBR 8800 (ABNT, [11]).

Dimension (mm) [1)]		A	m	Ix	Wx	rx	Xg	Iy	Wy	ry	lt	Cw
h x b x d	e	cm^2	kg/m	cm^4	cm^3	cm	cm	cm^4	cm^3	cm	cm^3	cm^6
100x50x17	2.65	5.74	4.51	89.59	17.92	3.95	1.78	19.74	6.13	1.85	0.13	475.74

Note: 1) The standard length is 6000mm per bar (considering e = thickness - in millimeters).

Source: Adapted by the authors from the ArcelorMittal technical catalog [12].

Maintaining strict convergence standards for numerical simulations aligned with computational modeling that meets design criteria yields satisfactory results for real project dimensioning. It is crucial to consider the arrangement and limitations of truss nodes, as well as the stiffness of the structural system, paying attention to degrees of freedom in the support region. These considerations align with the key findings of Abu-Khasan *et al*. [22], who emphasize that the roofing system is the most significant constructive part of any large building. The author notes that the stiffness in the vertical plane is about 45 times smaller than in the horizontal plane. Hence, conditionally, one can assume that a truss of this type will have one degree of freedom instead of two, accounting for potential project execution errors. In such cases, natural oscillation frequencies depend solely on the mass and additional loads like wind, a crucial consideration.

This work underscores the importance of meticulous attention to the design situation's specifics and the predictability of execution errors for better convergence of optimized dimensioning through numerical simulation. Implementing all safety coefficients of the standard is essential, achieved by modeling with the worst possible configuration for the object.

In Figures 13 and 14, the truss-type detail with profile section designations for all bars is depicted in 2D. This representation corresponds to the central roof and side roof of the Cultural Center, obtained from the final version of the roofing project generated by Cype3D software (2017). Additionally, Figure 14 displays a cut projection of the central roof's purlins, including section designations obtained through computational modeling in the final optimized version.

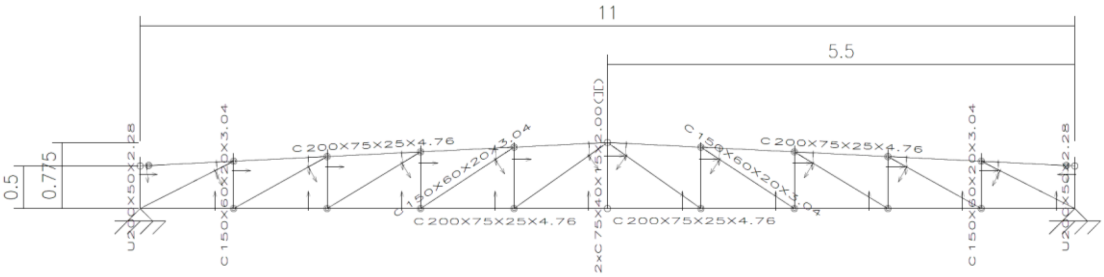

Figure 12. Designation of the profiles in the central roof truss.

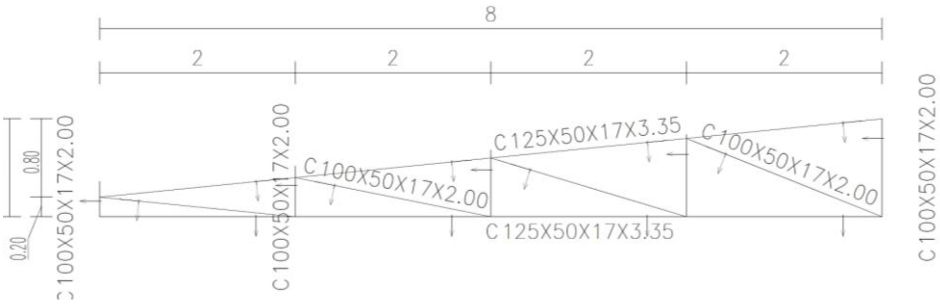

Figure 13. Designation of the profiles in the standard truss of the side roof.

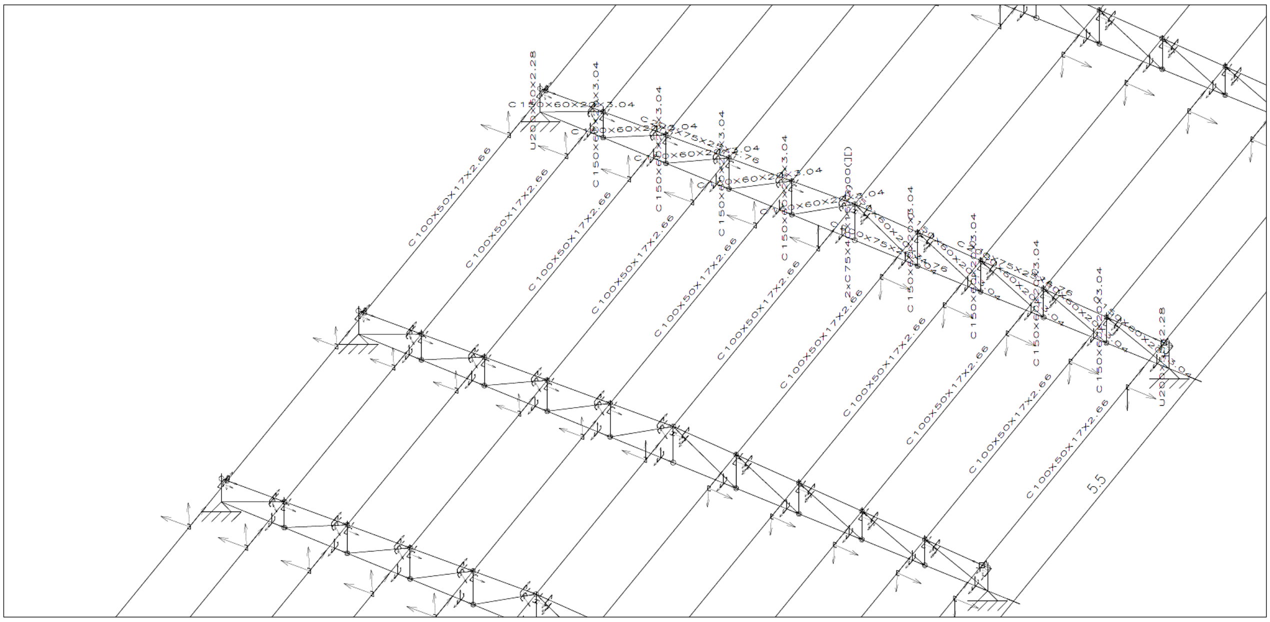

Figure 14. Detail of the positioning and designation of the central roof purlins.

IV. Conclusions

Through studies conducted in the construction and sizing phase of the metal structure covering the Commercial Center, it is possible to achieve the defined objectives and design a large-scale project.

This phase is presented and developed in accordance with current legislation and standards, ensuring the safety and quality of the work carried out.

In the overall project description, the proposal and characteristics of the Commercial Center are outlined. This facilitates the determination of normative requirements for project execution and related activities, including classification, permits, environmental licenses, and occupancy permits. In broad terms, the architectural design serves as a reference for the development of other projects, incorporating accessibility, safety, and functionality to best meet the requirements, always in compliance with current norms and laws.The roof project aims to ensure efficiency and comfort in development. The roofs are constructed with a metal structure, galvanized steel sheets, and compact polycarbonate to ensure the necessary safety and durability for rainwater drainage while providing natural lighting and architectural enrichment.

Therefore, the use of a metal structure for the Cultural Center roof is determined for this project scenario, aiming to span gaps and support the upper enclosure of the building. After verification and computational modelling, U-shaped steel profiles are adopted for both the truss bars and the rafters, and polycarbonate sheets with a reliability convergence safety level exceeding 96%. Additionally, it is emphasized that all component fixations must adhere to manufacturers' recommendations. Furthermore, certification is provided that the sizing and verification, assisted by the Cype3D software (2017), align with the recommendations of NBR 8800 (ABNT, 2008), assuming the same input data characterize the same project situation. Special attention is given to node and support constraints, as well as the degrees of freedom of the structure, ensuring safety with predictability of error in execution regarding the stiffness of the structural system.

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