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ASSESSMENT OF MECHANICAL BEHAVIOR OF THE HOWE, PRATT AND BELGIUM WOOD TRUSS TYPE OPTIMIZED BY THE METHOD OF GENETIC ALGORITHMS

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ABSTRACT

This paper presents the study of the optimized bi-dimensional wood structures, truss type, applying the method of genetic algorithms. Assessment is performed by means of a computer program called OPS (Optimization of Plane Structures). The purpose is to meet the optimum geometric configuration taking into account the volume reduction. Different strategies are considered for the positioning of diagonals and struts in the upper chord. It is concluded that the trussed system efficiency depends on the dimensions and the position of the members, where the purlin's location is not mandatory for struts and diagonal positions.

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1. INTRODUCTION

Wood is an organic material directly obtained from nature, that means, it does not require industrial processes in its formation. The energy spent in obtaining it, is practically related to the sawing of the logs. This way, if compared to concrete and steel, wood is a more advantageous material, because it requires a little quantity of energy for its formation and sawing. Besides this advantage, wood assembles other positive properties such as, good mechanical resistance both on tensile strength and on compression, good thermal and acoustic insulation, workability, resilience (capacity to absorb shocks) and low specific weight.

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However, wood presents some negative properties such as, vulnerability to fungi and bacteria, which associated to the lack of technical knowledge of the professionals in the civil construction area in Brazil, reduce its employment mostly in small works. On the other hand, investments in research in recent decades provided the market with preventive chemical treatments, which significantly reduce these vulnerabilities at low cost.

Only considering these aspects, even if superficially, it may be concluded that wood is technically viable as a permanent structural element. Like any other material, its employability depends on a structural arrangement able to leverage its positive properties making the structure technically and economically viable. An example of this can be found in the work of Góes and Dias [1] who studied the mechanical behavior of transversely prestressed wood bridges, demonstrating the possibility of applying the material, even when exposed to unfavorable environmental conditions.

The projects are developed to obtain functional structures that meet the specifications of technical rule. However, most of the engineering problems have more than one possible configuration to meet those demands and that requires the use of intelligent methods to achieve the optimized solutions.

For Rigo [2], the fast evolution of personal computers has been the motivation on research of new methodologies applied in structural projects and, particularly, the use and development of numerical algorithms more robust and efficient aiming to obtain structure strength. This has allowed the study of new structural arrangements or structural arrangements established, without the simplified assumptions required for manual calculation.

Based on current computer facility, one of the important techniques for calculation and sizing is the optimization of elastic and geometric parameters. For a better comprehension about structures optimization, basic differences between a conventional project and an optimum project must be enhanced.

When a conventional structures project is performed, the purpose is to obtain an adequate and acceptable configuration to their functionality requirements, usually ruled by a regulation, which is characterized by the direct influence of the designer, depending on his skill, background and intuition. That process is not always the most satisfactory. First, due to human failures and, consequently, for not providing the guarantees that the solution found is the best from the economical point of view.

In an optimization problem it is desirable to maximize or minimize a numerical function of several variables. As there is a need to identify the variables involved and their areas, as well as the relevant constants of the problem, the equation is made so that to determine the representation of the problem and its restrictions in the search for optimum solution. Therefore, the use of optimized systems leads to a better comprehension in structures sizing, once it modifies the physical aspect of the structure into a mathematical aspect, through a mathematical modeling of the structure analyzed. The classical optimization techniques are reliable and are applicable to different engineering areas, such as: projects of water supply networks, dosage of materials, managing transport routes, as well as in the optimization of structure projects, focusing mainly cost minimization. The papers[3-5] are examples of these applications.

In a structural project it is necessary to get a proper way to dispose the parts so that to enable the structure to safely bear the weight of the loading imposed, and implying in the lowest production cost. To achieve this goal, Lemonge [6] points out that information on topology, shape, cross sections and structure dimensions are required.

With the globalization of the economy, the decrease in structure costs in constructions becomes increasingly important. In the case of truss systems, which are light structures of quick and easy execution, the lower cost is due to the smaller volume of the structure. Therefore, the development of this paper is justified by the search for quality and economic structures, which are important parameters in any activity.

2. APPLICATION OF GENETIC ALGORITHM TO THE BIDIMENSIONAL WOOD STRUCTURES

2.1. Choice of structural models and function purpose

For the optimization results presented in this paper it was used the computer program called OPS [7]. Through the description of data entered into the program, and by successive iterations, the program optimizes the geometry of the structure in search for the optimum solution.

For the application of the optimization of the plane wood structures, it is necessary to first choose the structural model and then, to identify the constants and the variables of the project and to define the functions purpose and ability. In this paper, three models of plane wood structures were evaluated, as shown in Figures 1, 2 and 3.

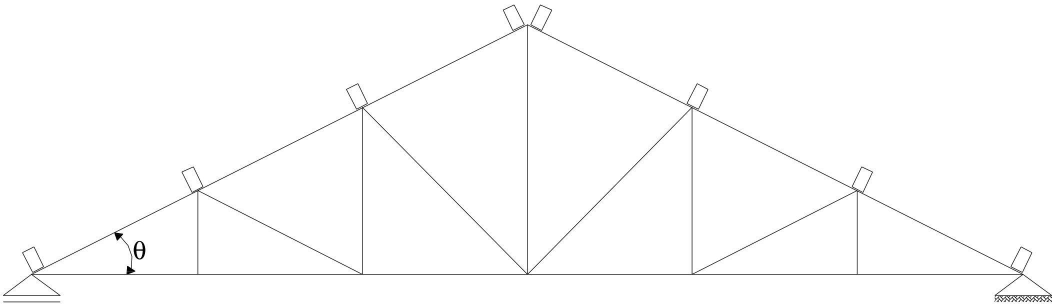

Figure 1. Howe truss

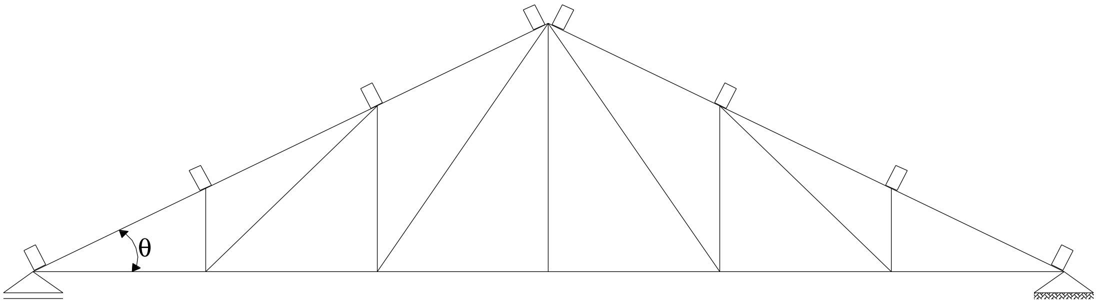

Figure 2. Pratt truss

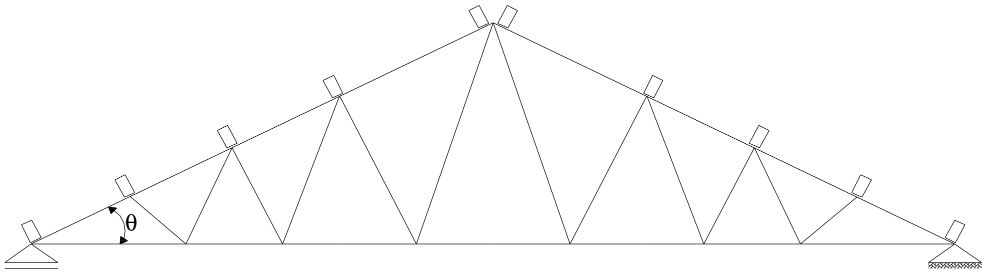

Figure 3. Belgium truss

The form chosen for the representation of the project variables was the genuine, because of the simplicity in implementing the code of the software OPS. The function purpose defined for the problem is the volume of wood, and the project constants are: roofing length (L), roofing width (W), height of the column (H), and the physical and mechanical properties of the materials. The project variables are: truss slope angle (θ), cross section area (A) that can be defined by the user or the ones available in the market and c_i (distance between two consecutive nodes in the bottom chord of the truss).

The span L can be represented by $2 \cdot \sum_{i=1}^{m} c_i = L$, where "m" is the half the number of modules of the truss.

It is important to point out that in the case of the Belgium truss the nodes in the upper flange are defined in the mean distance of the nodes in the bottom flange immediately before and after this one.

If the user chooses the cross sections available in the market, the parameter A (associated with the cross section dimensions) will assume the values registered in the program database, and then there will be only one variable, which corresponds to the position of the cross section in the database. On the other hand, if the user does not make this placing, he must provide the limits, inferior and superior, for the width and the height of the cross section, and in this case, there will be two project variables, the basis (b) and the height (h) of the cross section. That way, the software will have "2 + m" or "3 + m" project variables, respectively.

The function purpose is the wood volume for the construction of the structure with security, evaluated according to the Brazilian Code [8]. Considering that all the members have the same cross section, the function purpose for wood volume calculation is given by the eq. (1).

$$f = \sum_{i=1}^{n} \mathbf{l}_i \times A \tag{1}$$

where $\mathbf{l}_i$ represents the i_{th} length member of the structure and n is the total number of members.

2.2. Operation of genetic algorithm

As input parameters, OPS program needs the values for width and length of roofing, as well as the physical and mechanical properties of wood (Type and Class of wood), which are required for the calculation and dimensioning of the parts. It is also necessary to provide the program with the values of the slope angle, maximum and minimal (θ_{max} and θ_{min}) of the roofing planes and the number of modules in direction X (m_{max}). It is also defined if the trusses will have the purlins fixed on the strut. If not, the position of each purlin should be informed. For the elaboration of this paper, four cases were evaluated, with the purlins position defined and non-defined, as shown in Table 1.

It is noted that the value adopted for the lengths was fixed, only varying the width value. The slope angels, minimal and maximum, were of θ_{min} = 25º and θ_{min} = 45º, respectively. For the half number of modules in direction X (m) values between 4 and 7 were considered.

Table 1. Dimension adopted for the constants of projected cases analyzed

Cases	**Length (m)**	**Width (m)**	**Height of pillars (m)**
1	20.0	10.0	5.0
2	20.0	12.0	5.0
3	20.0	14.0	5.0
4	20.0	15.0	5.0

It was adopted wood of Dicotiledonea type, class C-60 and uniformly distributed loading (Figures 4 and 5). It is important to emphasize that during the optimization process, loading is modified into concentrated forces applied on the nodes of the upper flange, except in cases where the purlins position did not coincide with the strut. In these situations, the wind effect and the force owe to the tiles are modified into concentrated forces applied on the members of the upper chord.

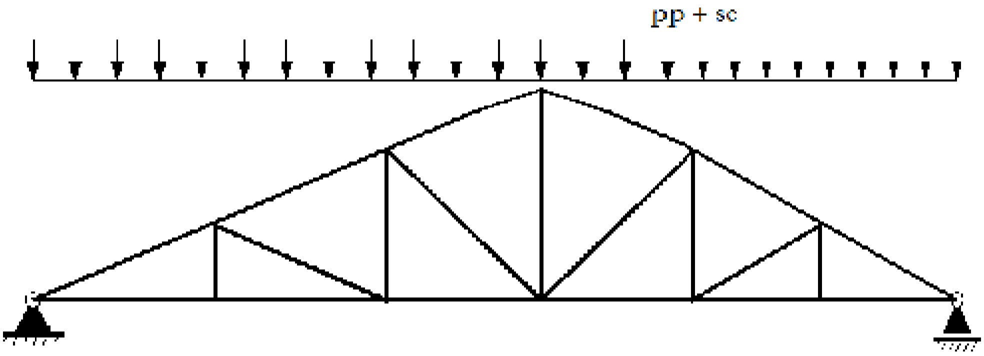

Figure 4. Loading of the structure by own weight action (pp) and overload (sc)

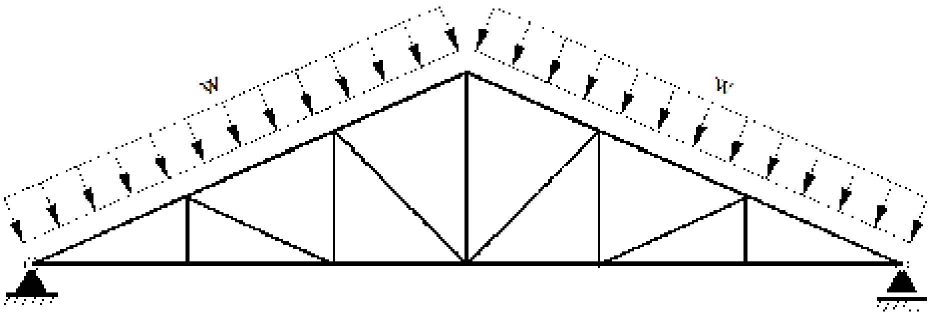

Figure 5. Loading of the structure by wind action

To perform the optimization of the structures, it was stipulated a population of 50 individuals interacting for 100 generations. The rates of recombination and mutation were of 0.80 and 0.05, respectively.

Once all the physical and mechanical properties of wood are known, the sizing is calculated verifying if the structure that better suit the problem in each generation meets all the criteria required by the Brazilian Code[8] for the limit states ultimate and service. If that does not occur, the structure is dismissed from the population, presuming its capacity index equal to zero. Then, the second better adapted structure is sized. This procedure is performed until one structure meets all the recommendations of the technical rule. Then, the genetic operators are applied: the roulette, recombination and mutation methods. More details concerning these operators can be found in papers elaborated by [9-10].

3. ANALYSIS OF MODELS EFFICIENCY

The purpose of the analysis is to find the structure with the geometric configuration that implies in the minimal wood volume. The adopted strategy for problem solution makes the optimized process directly linked to the mechanical behavior of the structure, since the restrictions are verified, the maximum nodal displacement and the sizing of all the members of the structure subject to flexion-compression or flexion-tension, according to Brazilian Code [8].

Three models of bidimensional trusses were analyzed, Howe, Pratt and Belgium ones, considering two situations: non defined purlin position – the OTF program immediately acknowledges that they are on the nodes of the upper flange – and, purlin position defined by the user. For the situation where the position of the purlin was defined, the values were set so that to be symmetrically distributed, as shown in Table 2.

Case 1 (10×20m)

Table 3 shows the results achieved in the optimization of wood volume of the structures evaluated for case 1.

Table 2. Results achieved in the minimization of wood volume (m^3) for case 1

Model	**Wood volume (m^3)**			
	m=4	**m=5**	**m=6**	**m=7**
Howe truss	0.1660	0.1347	0.1407	0.1449
Pratt truss	0.1660	0.1458	0.1560	0.1522
Belgium truss	0.1410	0.1468	0.1238	0.1220
Howe truss - defined purlins	0.1714	0.1905	0.1408	0.1414
Pratt truss - defined purlins	0.1966	0.2023	0.1507	**0.1199**
Belgium truss - defined purlins	0.1975	0.1419	0.1460	0.1569

Figure 6 shows the variation in wood consumption as for the optimum situation found, Pratt truss with purlins defined. The results show a variation up to nearly 70 %.

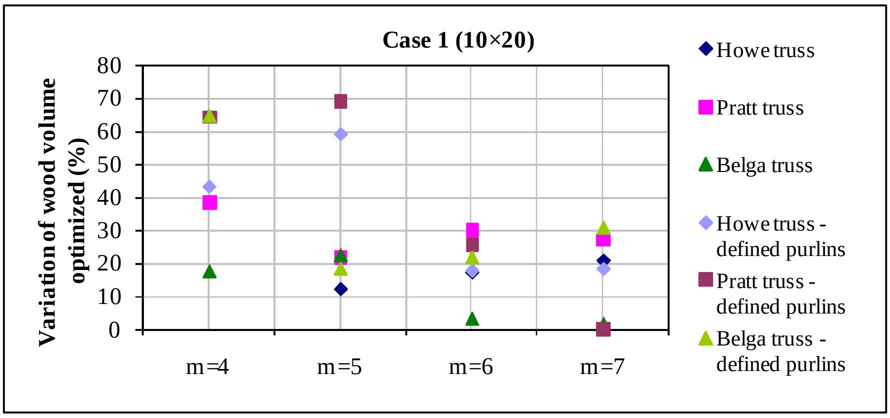

Figure 6. Variation of wood volume optimized for case 1(10×20m)

Table 4 shows the results of the optimized parameters of the structure with lower consumption of wood for case 1, i.e., Pratt truss with defined purlins.

Table 3. Optimized parameters of Pratt structure – defined purlins (Case 1)

Roofing slope	**25 º**
Cross section width	50 mm
Cross section height	50 mm
Wood volume	0.1199 m^3

Case 2 (12×20m)

Table 5 shows the results achieved by minimizing the volume of wood for the models of case 2.

Table 4. Results achieved in the minimization of wood volume (m^3) for case 2

Model	**Wood volume (m^3)**			
	m=4	**m=5**	**m=6**	**m=7**
Howe truss	0.5635	0.3426	0.2659	0.3310
Pratt truss	0.5493	**0.2428**	0.2599	0.3114
Belgium truss	0.2898	0.2662	0.2805	0.3003
Howe truss – defined purlins	0.5453	0.3155	0.3288	0.3323
Pratt truss - defined purlins	0.3360	0.3186	0.2779	0.3452
Belgium truss - defined purlins	0.3418	0.3564	0.2723	0.3031

It can be noticed in Figure 7 that wood consumption in some situations surpass 120 % regarding the optimum situation, Pratt truss without purlins definition.

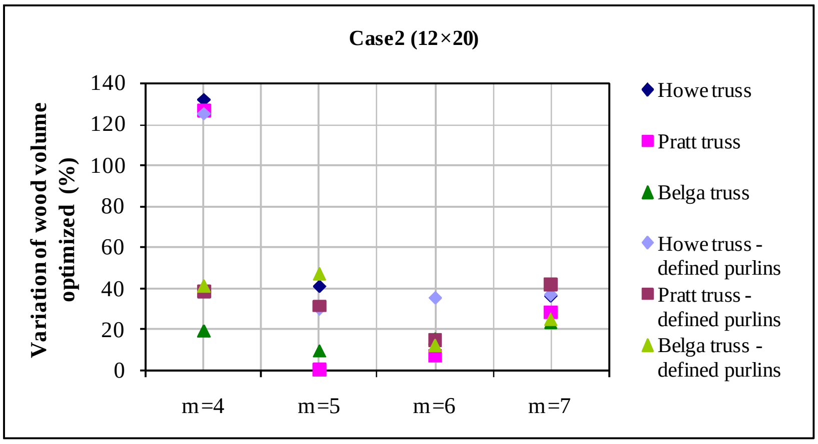

Figure 7. Variation of wood volume optimized for case 2 (12×20m)

Table 5 presents the results of the optimized parameters of the structure with lower consumption of wood for case 1, i.e., Pratt truss with purlins defined.

Table 5. Optimized parameters of Pratt structure with the lower wood volume (Case 2)

Roofing slope	18º
Cross section width	50 mm
Cross section height	110 mm
Wood volume	0.2428 m^3

Case 3 (14×20 m)

The results achieved in the structure optimization of case 3 are shown in Table 7. It can be concluded that Pratt truss, without previous definition of purlins position, presented the lowest wood consumption among all the situations analyzed.

Table 6. Results achieved in the minimization of wood volume (m^3) for case 3

Model	**Wood volume (m^3)**			
	m=4	**m=5**	**m=6**	**m=7**
Howe truss	0.6385	0.6536	0.6979	0.7205
Pratt truss	0.6607	0.6672	0.4189	**0.4055**
Belgium truss	0.6407	0.6569	0.6685	0.6903
Howe truss – defined purlins	0.6486	0.6531	0.7066	0.7390
Pratt truss – defined purlins	0.7066	0.6751	0.6874	0.7479
Belgium truss – defined purlins	0.6536	0.6707	0.6897	0.7162

It can be noted in Figure 8, that the variation of wood consumption for case 3 is also high, surpassing 60% in most of the situations analyzed.

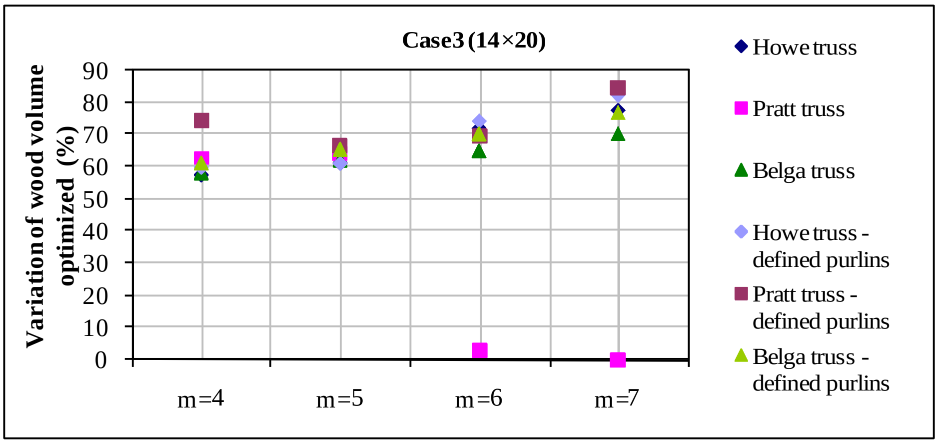

Figure 8. Variation of wood volume optimized for case 3 (14×20m)

In Table 8, it can be visualized the optimized results of the project variables that generate the structure with lower consumption of wood for case 3.

Case 4 (15×20 m)

Among the cases analyzed, case 4 was the one that presented lower percentages for the variation in wood volume. The critical situation presented a variation of 16%, as shown in Table 9 and Figure 9.

Table 7. Optimized parameters of Pratt structure – without defined purlins (Case 3)

Roofing slope	6 º
Cross section width	80 mm
Cross section height	200 mm
Wood volume	0.4055 m³

Table 8. Results achieved in the minimization of wood volume (m^3) for case 4

Model	**Wood volume (m^3)**			
	m=4	**m=5**	**m=6**	**m=7**
Howe truss	0.7235	0.7290	0.7247	0.7453
Pratt truss	**0.7038**	0.7326	0.7596	0.7911
Belgium truss	0.7077	0.7065	0.7366	0.7737
Howe truss – defined purlins	0.7205	0.7161	0.7780	0.7783
Pratt truss - defined purlins	0.7872	0.7213	0.7425	0.8175
Belgium truss - defined purlins	0.7076	0.7394	0.7407	0.7767

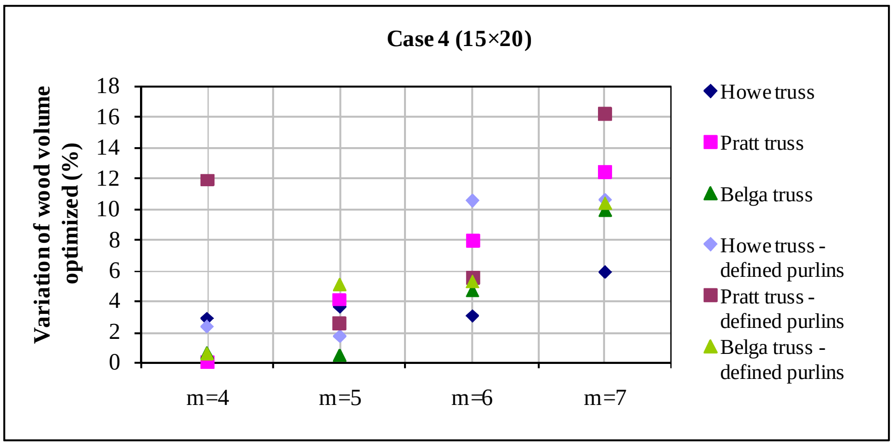

Figure 9. Variation of wood volume optimized for case 4 (15×20m)

Table 10 shows the optimized results for project variables, for case 4 with lower wood consumption (Pratt truss without previous definition of the purlins positioning). At last, for all the models amalyzed, the structure with lower wood consumption was the Pratt truss and only for case 1(10×20m), the lowest wood consumption occurred for the structure with purlins defined by the user; in the remaining cases the position of the purlins is linked to the optimized position of the struts.

Table 10. Optimized parameters of Pratt structure – without defined purlins (Case 4)

Roofing slope	**10º**
Cross section width	80 mm
Cross section height	200 mm
Wood volume	0.7038 m³

4. STRUCTURE DISPLACEMENT

It will be presented hereafter the results achieved for the displacement of Howe type structures with dimensions of 10m×20m. Structures without the positioning of defined purlins were considered and with the positioning of the purlins placed by the user, for cases of m=4 and m=5.

The results shown in Figures 10, 11, 12 and 13 illustrate the distribution of the members for each case. The displacements shown, generated by the computer program GESTRUT[11], are 10 times enlarged. In those figures are shown the structures undeformed (dashed) and deformed (colored).

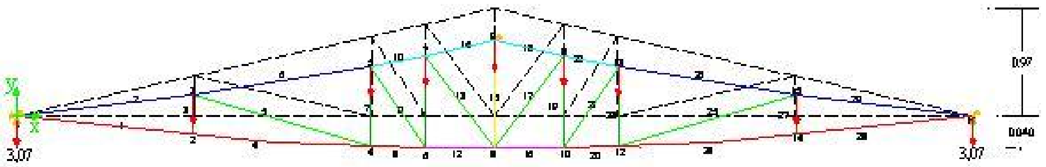

Figure 10. Displacement (m) of the Howe truss optimized with purlins coinciding with the pillars – m=4

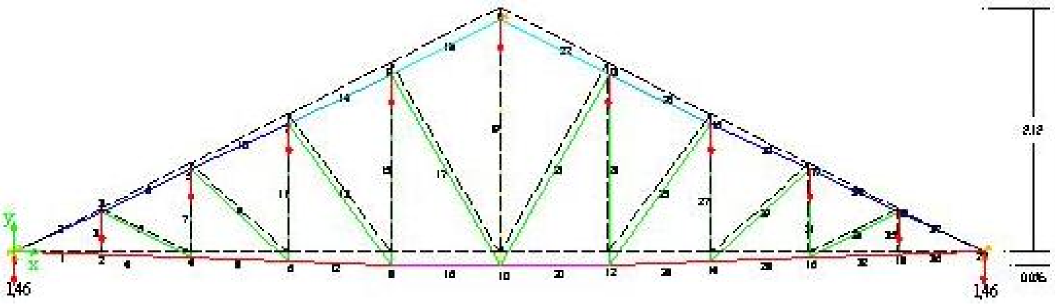

Figure 11. Displacements (m) of the Howe truss optimized with purlins coinciding with the pillars – m=5

It is important to note that the optimization of the structure in Figure 10, led to a configuration not much homogeneous concerning the distribution of the members, with concentration of members in the central area. This occurs because the optimization program searches a structure with smaller wood volume. Not always the structure found by the OTF program is the most viable constructively or aesthetically. However, as the members work with some spacing – which can be evidenced by the utilization rate – due to the availability of commercial sections, it is possible to rearrange the position of few members from the optimized structure, improving its distribution without significantly raising the prices of the result achieved in the minimization of the wood volume.

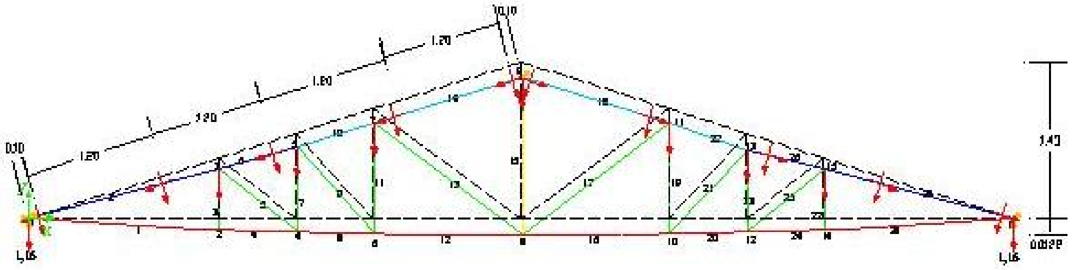

Figure 12. Displacements (m) of the Howe truss optimized with the positioning of the purlins placed by the user – m=4

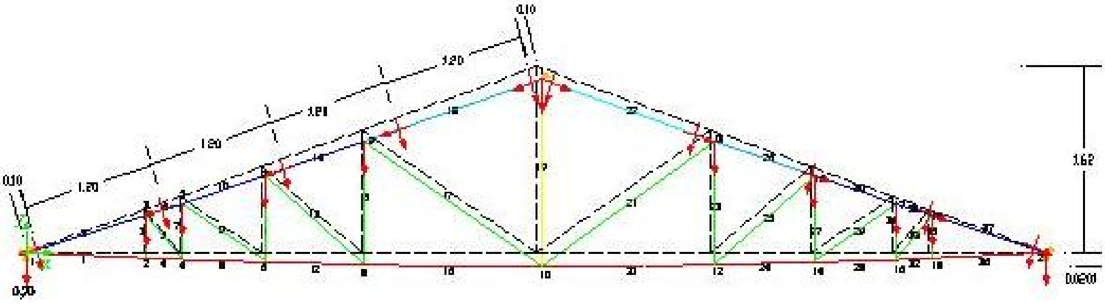

Figure 13. Displacements (m) of the Howe truss optimized with the positioning of the purlins placed by the user – m=5

Table 11 shows the summary of the maximum displacements achieved in all the four structures. Although the maximum displacements vary greatly from one situation to another, all the structures present displacements below the limit required by the Brazilian technical rule [8], which is L/200, i.e., 5cm.

Table 11. Values of the maximum nodals displacement calculated – downward

	m=4	**m=4 (defined purlins)**	**m=5**	**m=5 (defined purlins)**
Maximum displacement (cm)	4.06	1.22	1.63	2.01

5. CONCLUSION

Three types of plane trusses, of the type of gable roof, were studied applying the AGs method in the minimization of wood volume. The assessments were performed for four different cases for the relation length/width of the covered area.

The project variables that most significantly influence the function purpose (wood volume) are the number of modules towards X direction and the cross section dimensions of the members. As seen from the results, a structural wrong choice may represent a very significant increase in structure cost. For case 2, this increase exceeded 120%. Thus, for each problem it is necessary to accomplish the optimization process to determine the optimum solution.

It is also confirmed that, when the purlins position are adopted in the structure, normally the optimum wood consumption increases when compared with the same case in which the purlins position coincide with the struts. However, the imposition of the purlins in an optimized structure corresponds to a more realistic condition, as the spaces between the purlins are defined considering the type and size of tiles.

Finally, for the cases examined, the Pratt model presented the best results, i.e., smaller wood volume.

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