# Applying CAD/CAE/CAM Techniques for Optimizing the Design and Reducing the Cost of a Pediatric Stander

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## Abstract

A pediatric stander is an adapted piece of equipment whose function is to achieve the vertical position of the child when motor control is inadequate, in other words, when the child cannot stand and control his weight against gravity, having the age to do it. This technical equipment is necessary for patients diagnosed with cerebral palsy who have already acquired head control and initiated trunk control. This product has a high value in Peru. For the generation of this equipment, we will apply a computer editing and design process, we will follow a 5-step process in addition to applying CAD, CAE, and CAM techniques, emphasizing the design optimization method. Finally, we will verify how the application of this methodology, together with computer simulation, allows us to generate a functional, resistant prototype and, in the main point, with optimization in design and acquisition costs.

## Keywords
Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), Computer-Aided Manufacturing (CAM).

## 1. Introduction
Cerebral palsy (CP) is defined as a disability that affects the movement and posture of the body. It is a disorder that consists of a set of permanent disorders that affect various areas of the body, which limits the activity of the body and are produced by non-progressive lesions that occurred while the central nervous system was developing. Likewise, this disorder can present alterations such as sensitivity, behavior, communication, cognition, perception, and psychological problems.(Garita Meneses et al., 2020; Occhipintti & Mendoza, 2018; Vila Paucarcaja et al., 2016) In addition, it can be classified into three types depending on the area of the brain that is affected, which are: spastic paralysis, ataxic paralysis, and athetoid paralysis.

In Peru, a study conducted at the Cayetano Heredia National Hospital in 1993 showed that the incidence of CP in live newborns had a prevalence of 5.2 per 1,000, but currently, the frequency of children with CP has increased due to increased survival of outpatient preterm infants and to decreased infant mortality.(Vila Paucarcaja et al., 2016). Among the various applicable treatments to seek an improvement in muscles and positioning, techniques known as a pediatric stander, orthoses, or adapted equipment are used to achieve the vertical position.

This article is focused on the pediatric stander, oriented to the Peruvian reality, where the different cultural, social, and economic characteristics show that a large part of the minority of the population, such as patients with cerebral palsy, and even worse, children with this disability do not have the necessary means to acquire adequate treatment. To solve the described problem, this scientific research is focused on the use of the design optimization method to be able to produce a pediatric stander, seeking to satisfy the needs raised. All this with the help of computer-aided design (CAD), computer-aided engineering (CAE), and computer-aided manufacturing (CAM) programs.(N. Cobetto et al., 2016; Nikita Cobetto et al., 2017; Frizziero et al., 2021; Guy et al., 2021; Heo et al., 2021; John Ignacio et al., 2019; Lopez et al., 2020; Matuda et al., 2021; Naddeo et al., 2018; Sosa-Méndez, 2016; Wang et al., 2016) The scientific articles reviewed on this methodology give us good information to be able to use it in the best way to satisfy the stated need.

## 2. Literature Review

In Peru, there are difficulties in the health system for the treatment of children with cerebral palsy, plus the shortage of therapy equipment, such as pediatric standers. These support teams are difficult to obtain in Peru in the first place because of their high cost, since they are imported, they present import taxes and their respective freight. Secondly, due to the lack of a national market focused on this sector with the implementation of technology in design. Given this, this article presents the application of the Design Optimization Methodology together with the CAD, CAM, and CAE Techniques, which are currently used more frequently for the design of orthopedic devices and have proven to be so effective in comparison. with the traditional methods of plaster, using metrics in two dimensions.(Nikita Cobetto et al., 2017) Next, the tools, elements, and activities to be developed for the entire production process of the pediatric standers will be explained with the help of the reviewed literature.

### 2.1 Computer-Aided Design (CAD)

From its inception in 1990 onwards, computer-aided design (CAD) tools have had a considerable impact on industrial designers and their jobs. With the rapid development of technology and the advancement of this tool, industrial designers can quickly display, modify and generate three-dimensional designs on computer screens with high resolution. Thanks to this, not only an industrial designer can potentially generate a large number of detailed designs very quickly, which in other words means that they can achieve more innovative design solutions. As can be seen in the following literature where this tool is used to design a surgical template (Cristalli et al., 2020; Wang et al., 2016), surgical planning of cubitus varus in children (Heo et al., 2021), and also for solutions dental (N. Cobetto et al., 2016; Sosa-Méndez, 2016). For this article, the components of the pediatric standers are made piece by piece with this tool.

### 2.2 Computer-Aided Engineering (CAE)

The CAE tool is the extensive use of computer-aided programs that help in the engineering analysis task. These programs include Finite Element Analysis, Computational Fluid Mechanics, Optimization, and Multibody Systems. The purpose of this tool is to analyze the robustness and performance of components either by part or as an assembly. The term encompasses product validation, simulation, and optimization. The most frequently used analyzes in mechanical engineering for CAE simulations are the following: Applied forces, pressure, temperature, and component interactions. Within the reviewed literatures, the most used program is the finite element analysis (N. Cobetto et al., 2016; Nikita Cobetto et al., 2017; John Ignacio et al., 2019; Lopez et al., 2020; Sosa-Méndez, 2016). Thanks to this tool in these articles, it was possible to validate the functionality, resistance, and durability of the exposed cases.

### 2.3 Computer-Aided Manufacturing (CAM)

Computer-aided manufacturing is defined as the use of a computer program that controls the machines, tools, and other machinery involved in the manufacturing process. It is the most technical part of the process as it is involved with machinery and production. CAM can also refer to the use of computers to support all factory operations, including planning, transportation, management, and warehousing. The purpose of this tool is to create a faster production process with more precise components and tools, reducing the margin of error. This is the last process to be carried out within these tools once the design has been carried out and its resistance has been validated. Thanks to the CAM tool, the G Code of each process is generated, which is passed to the machines that manufacture the products, these are the numerical control machines (CNC), of which the following stand out: milling machines, lathes, laser cutters, engravers, etc. Within the reviewed literature, this tool is widely used to carry out a good production of the prototypes to be manufactured (Ali et al., 2020; N. Cobetto et al., 2016; Nikita Cobetto et al., 2017; Cristalli et al., 2020; Frizziero et al., 2021; Guy et al., 2021; Naddeo et al., 2018), managing to reduce any type of failure or miscalculation. Within this article, it will be used to simulate the creation of the pieces thanks to tools and machines within the computerized software, as well as to create the corresponding G Code to take it to the manufacturer in a CNC machine.

## 3. Methods and Application

For the treatment of various diagnoses that require the use of an orthopedic prosthesis or surgical implant, technology is currently used to optimize the design of these pieces of equipment or parts and minimize errors that could have a negative impact on patients. In the same way, development and design in a way that minimizes the chances of errors in both manufacturing and assembly. For this, in what is investigated, CAD, CAE, and CAM techniques are presented for optimal design and development.

### 3.1 Proposed Model

The model will be developed in 5 phases in total as presented in Figure.1. Next, we will present each phase in detail.

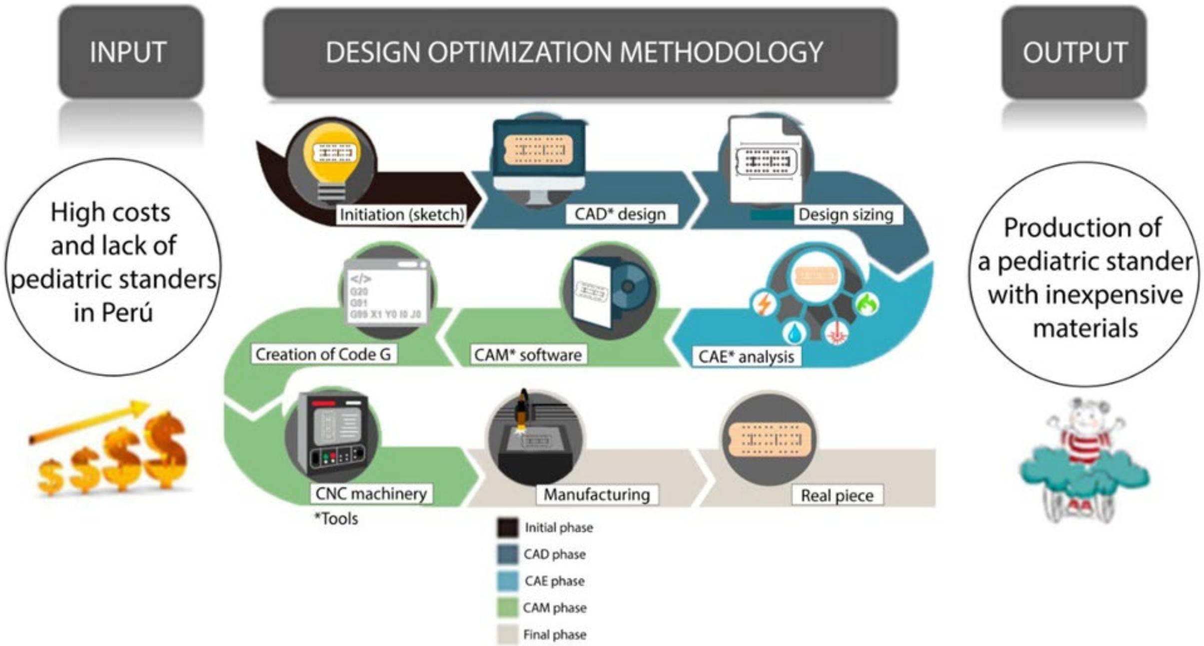


Figure 1. Proposed model

*1)* ***Initial phase*****:** This phase includes all the activities before the design of the model. Begins with a study of the basic needs that a standing frame requires in order to develop one with good functionality and safety for the user, without omitting the main point of the investigation, which is the reduction of the cost of its acquisition. Therefore, surveys were used for parents, specialists and the children with cerebral palsy who were able to interact directly with us. Thanks to these surveys, we carried out an Empathy Map that generates a more direct image and qualitatively recognizes those essential needs of the respondents. Subsequently, a function-requirement table was prepared where the influential requirements were highlighted, which are: Comfort, Visualization, Practicality, Transportability, Safety, Ergonomics, Ease of use and Monetary value. Finally, it was possible to elaborate a quality home chart to see the needs that a good standing frame requires. In this way we establish the requirements that are requested for the correct design of a standing frame: Comfort, Visualization, Practicality, Transportability, Safety, Ergonomics, Ease of use and Monetary value. The most influential requirements will be recognized with the table 1 of functions - requirement. Recognizing the influence of the requirements along with obtaining the problem, thanks to this information, we subsequently obtained indicators aimed at responding to the needs and problems presented by both parents and minors as well as related professionals.

Likewise, an interview was conducted with a technical specialist from the INABIF institution in Peru to corroborate these results and improve the details that involve the first step of the design optimization methodology, which is the sketch of the standing frame. Said sketch had several versions and variations in its physical form, since the implementation of the pressure fit design technique is sought, which is the design of each piece of equipment to be joined by pressure without the implementation of nails or screws.

This stage is also where the materials to be used in the standing frame were chosen, which are:

1. Medium density phenolic plywood boards with a thickness of 18 mm, which present a smooth and homogeneous surface, also present great versatility of applications that allow obtaining excellent finishes and have an ideal density and uniform behavior for molding, curving, fixing milling, among others.
2. Swivel sheaves with a platform measuring 2 ½” with the capacity to support 50 kg each, two of them with brakes for the rear part and two without brakes for the front part.
3. Hex bolts and nuts measuring ¼ x1 ½”
4. LAF electro-welded carbon steel tube (cold rolled) with an external diameter of 1 1/8”.

5. Cushions with adjustable plastic buckles and straps to be tied (table 1).

Table 1. Table of functions – requirement

| | | Stakeholders | | | | |
|---|---|---|---|---|---|---|
| Requirements | Functions | S | C | F | Importance | Functional Order |
| Comfort | Presence of the well-being of the child on the pediatric stander. | | 1 | 1 | 0.6 | 5 |
| Display | Pretty to look at. | | 1 | 1 | 0.6 | 8 |
| Practicality | It is not bulky, nor does it take up much space. | 1 | | 1 | 0.8 | 4 |
| Portability | It is easy to transport. | | | 1 | 0.4 | 1 |
| Security | Avoid injuries or accidents due to imbalance of the pediatric stander. | 1 | | 1 | 0.8 | 7 |
| Ergonomics | Easily adjusts to the child's body. | 1 | | 1 | 0.8 | 6 |
| Easy to use | Minimal difficulty in handling. | 1 | | 1 | 0.8 | 2 |
| Monetary value | It's low cost. | 1 | 1 | 1 | 1 | 3 |
| | | 0.4 | 0.2 | 0.4 | 1 | |
| *C = Child | F = Fathers | Stakeholder Priority | | | | |
| S = Specialists | | | | | | |

*2) **CAD phase***: Thanks to the sketch, the computer-aided design of this is carried out with the help of the Autodesk Inventor Professional program, where the relevant properties and characteristics were specified to be able to design the standing frame, all this thanks also to the information provided by INABIF on the sizes, which They vary depending on the type of paralysis that the child presents, but they are between 110 cm and 150 cm, and the weight of children who are between 20 kg and 60 kg. With this, the pieces began to be sized and designed to a standard size for use, which was approximately 130 cm high to be able to hold the infant's body well. Once the size of the equipment was established, the handmade drawing began to be broken down to be designed piece by piece in an exact manner, starting with 2D lines to later use a model transforming them into 3D and also giving it some aesthetic details, such as contours or pockets, among others. This process was used one by one in the 14 different pieces that make up the standing frame, which must be perfectly sized to be compatible with each other.

Once the design of all the pieces that are part of the standing frame was completed, the assembly of these was carried out using the same software, where the coincidences and fittings of the pieces began to be made one by one by means of the pressure adjustment technique until reaching to have a 3D rendering of the real model of the assembled standing frame's phase: Analysis of force and pressure to the pediatric stander already assembled and with a defined material (using the Autodesk Inventor Professional program). If necessary, redesign to make it an optimal and functional equipment. Finally, in this phase, once the 3D rendered graphic representation of the equipment has been obtained, the three respective views can be seen.

*3) **CAE phase:*** In the CAE Phase we perform a force and pressure analysis on the already assembled standing frame, which is an indicator. The material of each piece of the standing frame was established in this part before carrying out the study so that a simulation as real as possible to reality, all this also in the Autodesk Inventor Professional program in its stress analysis section. Once the materials were established, the lower part was applied as the fixed point of the standing frame, which is the base and carries all the weight, so that it remains still. Subsequently, the forces began to be applied to each part of the equipment, knowing that the maximum weight of a child in these qualities is 60 Kg, these forces were transformed and applied in Newtons correspondingly according to the angle at which the point of contact of the material, being the force of 588 N the strongest applied in the central part.

The result of this analysis can not only be seen numerically with the data provided, but it was also possible to see graphically how the prototype would behave with said applied forces and how its materials would buckle, all this at color scales. This scale goes from blue to red, where blue means that it perfectly resists the analyzed object and red means that the object has many possibilities of losing its continuity or of not serving what it is being designed for, all this in the unit of measure of Mpa.

*4)* ***CAM phase:*** In the CAM Phase, the technical process of manufacturing the standing frame begins, simulating the production of each piece with the use of virtual tools to analyze how it would be when produced and thus be able to generate the G Code (the most used programming language in control numerical) of manufacture of each piece. In the first place, the 3D pieces are returned to 2D and are optimally accommodated all in the same plane within a rectangle that simulates the phenolic plywood board, this is done to have the cutting lines of the pieces. Once the arrangement of the pieces is finished, the Aspire software is implemented to calculate the tool paths to generate the G Code. Once the creation of the G Code of all the pieces is finished, it is entered into the selected CNC machine., which is a CNC Router of the Multicam 3000 model located at the University of Lima, which allows the manufacture of real-scale prototypes by milling wood, aluminum and acrylic, among others, since it has a 3.6 x 2 table meters with 8 interchangeable tools. After implementing the code to the machine, we proceeded to make the adjustments of speeds and the tool to be used.

*5)* ***Final Phase:*** In the Final Phase of the model, considering the Idea approach, the design and dimensioning of the CAD, the CAE analysis and the generation of the CAM modeling code. The cutting of each piece of the standing frame begins with the help of the Multicam 3000 CNC machinery for a period between 45 to 50 minutes.

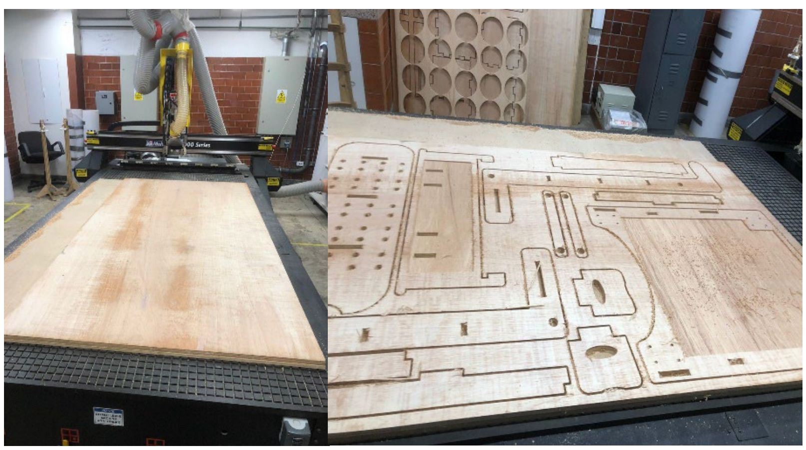

Figure 2. Start and end of the cut with the CNC machinery

Once the machine finished its work and with the pieces (Figure 2), all the same as how they were designed, the standing frame was assembled in order to have the final finished product. Once the standing frame was assembled, the final details of cleaning the components were given to have a product with a pleasant view.

## 4. Data Collection

To validate our research, we decided first to recognize the value in the international market of different brands of standing frames that are made of different materials such as carbon steel, stainless steel, and high-density plastics that, built with similar characteristics, are normally purchased by companies. people or organizations that request them. Among which are the models: Parapion, Dondolyno, Cat 2, Buffalo and Standy. Which have an average price of 1837.12 USD. In the following table 2, we will present some of these models, which in comparison show a vision of the existing market and real costs (in US dollars).

Table 2. Market Values of draft standing frame models

| Standing frame Model | Cost in Dollars (USA) | Cost in Soles (PEN) |
|---|---|---|
| Parapion | 1500 | 5880.00 |
| Dondolyno | 1541.89 | 6044.21 |
| Cat 2 | 2393.2 | 9381.34 |
| Buffalo | 2143.16 | 8401.19 |
| Standy | 1607.37 | 6300.89 |

As could be seen, the models of standing frames are found in acquisition costs ranging from 1,500 USD to amounts greater than 2,000 USD. As we are aware of this reality and of the existing need for the treatment of minors, we seek that the model that is produced thanks to the support of our design optimization methodology together with the recognition of material costs that we will present in the following table 3, allows generating a change in the local image about the probability of being able to follow an effective treatment and at a lower cost than the existing one.

Table 3. Cost of materials

| Materials | Quantities | Unit price in Soles (PEN) | Cost in Soles (PEN) | Cost in Dollars (USD) 3.94*PEN |
|---|---|---|---|---|
| Phenolic plywood18mm 1.22 x 2.44 | 1.5 | 139.9 | 209.85 | 53.26 |
| Caster wheels 2 1/2" | 2 | 16.9 | 33.8 | 8.58 |
| Caster wheels whit brakes 2 1/2" | 2 | 19.9 | 39.8 | 10.10 |
| Hex Bolts and Nuts Pack CG2 1/4x1 1/2" | 4 | 5.1 | 20.4 | 5.18 |
| Carbon steel tubes 1 m | 1 | 20 | 20 | 5.08 |
| Adapted cushions | 3 | 33 | 99 | 25.13 |
| | | | 422.85 | 107.32 |

Added to this total, the price of CNC mechanized cutting in the local market would be 2 soles per minute. Considering that the design of 2 boards would be carried out in a time of between 45 to 50 minutes, the manufacturing cost would come in a margin of between 90 to 100 PEN. In this way we determine that producing a standing frame on one's own, applying the proposed methodology, would not lead to a personal investment of 522.85 PEN or the probable change of 132.70 USD. Thanks to this result, we can make an important comparison as an indicator in the results after analysis. It is between the value obtained from our own production, applying our study and methodology, and the percentage that it would represent of an average value between the previously presented costs of the other models.

$$\frac{Average\ Market\ Cost - Cost\ of\ the\ metodology}{Average\ Market\ Cost} x100$$

Through this formula, we will obtain the percentage value that would represent the cost calculated with the implementation of the design optimization methodology against the average cost of the market.

# 5. Results and Discussion

## 5.1 Numerical Results

Thanks to the average price of the pediatric standers on the market, which is 1827.12 USD, together with the cost of the methodology, the cost reduction indicator was made, with which the following percentage was obtained:

$$\frac{1837.12 - 132.70}{1837.12} x100 = 92.77\%$$

Taking into account the result being 92.77%. It is demonstrated in high clarity that within the implementation of the proposed methodology, the result obtained is considered favorable, which indicates that it was possible to reduce a large amount of monetary investment in the acquisition of this technical equipment.

### 5.2 Graphical Results

The following result is thanks to the CAE indicator that was carried out in the Autodesk Inventor Professional software in its stress analysis section, where various forces distributed around the standing frame were applied, varying from 147 N to 588 N, this being a maximum equivalent to 60 Kg. This added to the analysis of the Von Mises stress that analyzes the ductility of the materials simulated in the program which allows us to visualize the following figure.

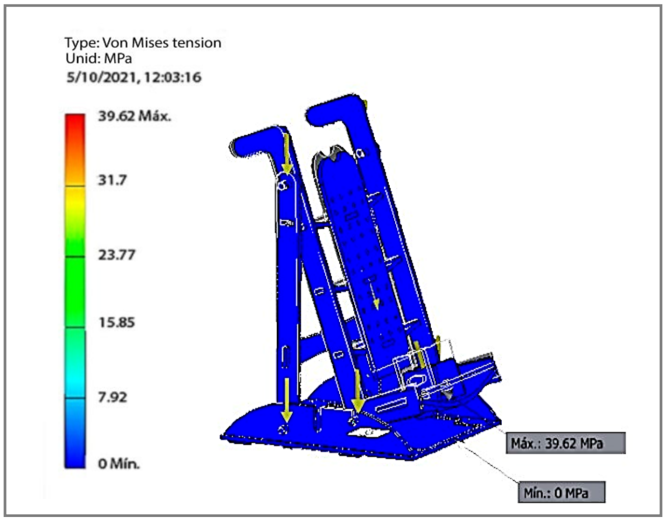


Figure 3. Von Mises stress analysis

After what is displayed, the blue color that the standing frame presents represents that the material is within the lowest range of deformation thanks to its ductile properties against the applied forces. The values on the team's analysis fluctuate between 0 and 7.92 MPa, these being within the color already mentioned in the color scale. You can also see the buckling of the material at a maximum point without reaching its loss of continuity, with the transparent contour being the minimum buckling and the blue body buckling as the maximum.

### 5.3 Proposed Improvements

Considering the results obtained and the comparative advantage towards models in the market, we recognize that among the factors that would require some additional improvement, the weight of the equipment (18.8079 kg) was obtained thanks to the simulation of the software used in the stress analysis, could be optimized by implementing materials that would be more resistant, flexible, and lighter, such as carbon fiber in comparison. Despite recognizing that carbon fiber would mean an additional cost in the development of this equipment, it would not have a significant impact since, in the application of the numerical results indicator, it would not decrease from the calculable 80%.

Another situation that we could take into account is that thanks to the Autodesk Inventor Professional design software we can ensure flexibility in the design of this equipment taking into account the requirements or needs of both the minor and their parents.

### 5.4 Validation

Having seen the results obtained going from the initial phase to the final phase, the benefit of the application of the design optimization methodology would be expressed in the value of the safety coefficient that the design software gives us. This coefficient allows us to recognize the maximum capacity that the designed pediatric stander presents versus the real capacity to which it will be subjected. In the following figure 4, we can see the maximum and minimum of this coefficient in a color scale.

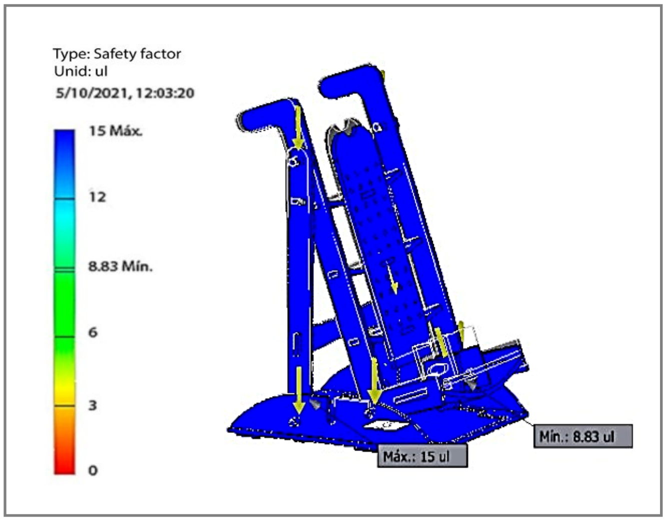


Figure 4. Safety factor

As can be seen in the figure, the safety coefficient has a minimum value of 8.83 and a maximum value of 15, which are within the color scale between blue and light blue that express optimal results. This means that the safety of the equipment can drop to 8.83 with the application of the applied forces that simulate the weight of the child, but even so it is within a value far from 0 and close to 15. In other words, it can be said that the equipment is safe for use, which is the most important requirement for the creation of the pediatric stander.

## 6. Conclusion

After what was presented through the design optimization methodology used in this work compared to the real models in the market, it was achieved that, in the first place, the cost/benefit ratio proves to be more than optimal with a percentage of 92.77 of savings for the user or organization that is interested in acquiring a pediatric stander concerning the local reality. Secondly, the implementation of specialized software, such as Autodesk Inventor Professional and Aspire, demonstrated a great facility for effective and efficient execution of objectives to be met, allowing direct results to be obtained for the allowable stress limit for the material (from 0 at 7.92 MPa) and the safety coefficient (Min. of 8.83), the latter being the indicator that gives way to its manufacture.

On the other hand, knowing that in the local reality it is not so easy to acquire the cutting services of a CNC machinery, it was considered that it is possible to choose to carry out the same method until the CAE phase, wherewith the help of the plans obtained in the CAD cuts and fabrication can be made with a manual jigsaw. Although precise results such as those provided by the CNC machine are not achieved, the final objective is achieved.

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## Biographies

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