ENGINEERING AND ARCHITECTURE DEPARTMENT

DEGREE IN MECHANICAL ENGINEERING

REDESIGN OF A CLASSROOM CHAIR FROM THE CAMPUS OF PARMA

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Abstract

Many university students may suffer some kind of illness or musculoskeletal disorders, or simply discomfort in the classroom, caused by the long time they must remain seated in its chairs.

The study consists of improving the ergonomics of a classroom chair at the University of Parma, studying the anthropometric behavior of users when sitting on the chairs. For this, we will use several methods that evaluate different postures that the student can adopt. We will focus on three methods: RULA, REBA and OWAS.

From the data obtained, we will evaluate the ergonomics of the old chair and we will propose a series of improvements, which will be applied in the redesign of a new chair.

We will propose an ergonomic study using the Catia program to both chairs, to realize the improvements applied to the new one, as well as a mechanical study, choice of new material, costs...

1.- Introduction

In this work has been carried out the redesign of a chair of the University of Parma.

Due to the large number of hours spent by students sitting in the classrooms, the correct design of school furniture is very important, which implies a good ergonomic design of the same.

The fatigue in the classroom, lack of attention, back pain and musculoskeletal disorders, are due to the poor postures adopted by students, which is why ergonomic aspects play a crucial role in school furniture.

Therefore, the main purpose in the development of this work is to improve the ergonomics of a chair of the University of Parma, since students spend many hours sitting in them, and many of them express the discomfort of them.

A brief historical review is made on ergonomics and on the different methods of evaluation of the postures adopted by the users.

A brief review is made of the legislation applied to ergonomic aspects in school furniture, as well as a search of the different patented chairs for academic use.

A method of flowchart is proposed that we will follow for the redesign of the chair. It starts by measuring the chair that will be redesigned and taking data from the different postures adopted by the students in them. A 3D modeling of the chair with Inventor is continued, evaluating the postures through three observational methods RULA, REBA and OWAS and performing an ergonomic study with Catia.

A series of critical parameters are considered in the redesign of the new chair and together with these and the previously obtained results, a series of improvements for the new chair are proposed.

For the redesign of the new chair, 3D modeling of the new chair with Inventor is carried out, evaluating the RULA, REBA and OWAS positions through a theoretical analysis, a later ergonomic study with Catia and a cost study of it.

It ends with a comparison between the old and the new chair.

2.- State of the art

This chapter includes a brief historical review on ergonomics, a subsequent introduction to the different types of ergonomic methods with the consequent development of the most used methods for evaluating postures at work. Finally, the legislation applicable to study chairs is included.

2.1.- History of Ergonomics science

The concept of ergonomics arises from the union of two Greek words, "ergon" (work) and "nomos" (law o rule).

The concern of man for the worker has always existed, for this reason, the need to adapt the tools of work to man. If we briefly review the history, we can quote Vauban in the century XVII, and Belidor in the century XVIII, who tried to measure the daily physical workload during the exercise and the workplace. Afterwards Bernardino Ramazzini, who is considered father of the work medicine for writing the first treatise on workers' diseases.

There have also been different researchers who have been scientifically interested in man to understand him from Physiology, Chemistry, Anatomy, etc. as Leonardo da Vinci, Lavoisier and Coulomb [1].

In 1857 was the first time that the term ergonomics was used, by the polish scientific W. Jastrezebowski in his work called "ergonomics and work science based on truths taken from nature", he is considered the father of ergonomics [1].

Although there had been previously research on this subject, it was during the Second World War, in the United States, when the need to adapt the task to man arose. This led to an action that was called "human engineering", in Europe this activity is called ergonomics. The current conception was born in 1949 thanks to Professor KFH Murrel who created the first national society of ergonomics, the "ergonomics research society" [1].

The ergonomics research society defines the ergonomics as "the scientific study of human factors in relation to the work environment and the design of equipment (machines, workspaces, etc.)" [1].

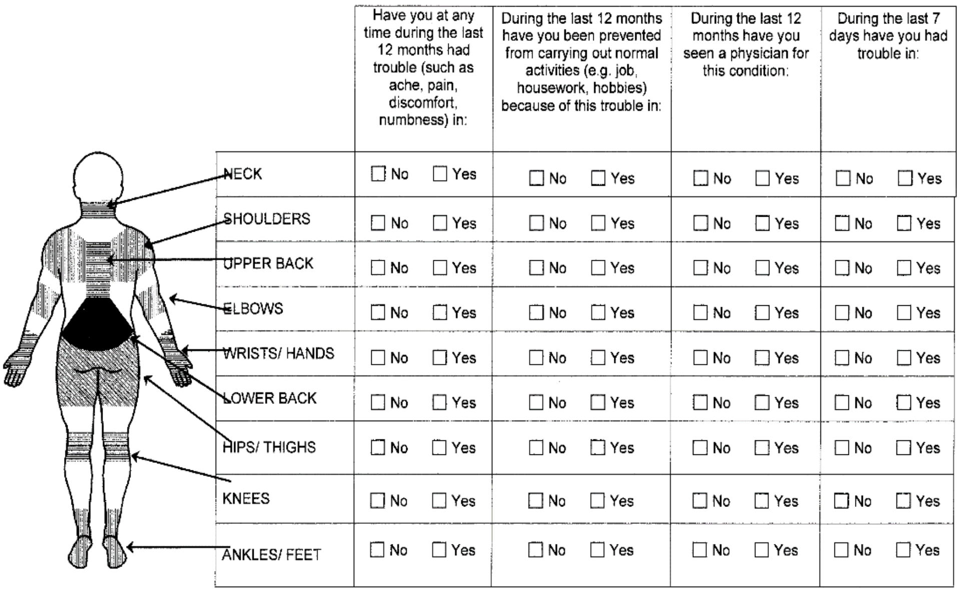
2.2.- Ergonomics in Engineering

In ergonomics, the posture and movement of a worker are important information for determining the risk of musculoskeletal injury in the workplace. Different methods and tools have been developed to assess exposure to risk factors for work-related musculoskeletal disorders (MSDs, which are injuries and disorders of the musculoskeletal system), and for assessing physical load.

The methods can be divided into three groups [2] according to the measurement technique. They are the self-report, direct measurement and observational methods.

1. Self-report methods evaluate the postures of the workers by rating scales, questionnaires, checklists or interviews. Its advantages are: its easy use, applicable to a great variety of situations at work, and to a large number of subjects at comparatively low cost, however, these methods are not always reliable and could lead to biased interpretation.

   Large samples sizes are necessary to ensure that the collected data is representative of the sample. In addition, these methods depend on the levels of literacy, comprehension or question interpretation. Figure 1 shows an example of a questionnaire to evaluate musculoskeletal disorders.



	Have you at any time during the last 12 months had trouble (such as ache, pain, discomfort, numbness) in:	During the last 12 months have you been prevented from carrying out normal activities (e.g. job, housework, hobbies) because of this trouble in:	During the last 12 months have you seen a physician for this condition:	During the last 7 days have you had trouble in:
NECK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
SHOULDERS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
UPPER BACK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
ELBOWS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
WRISTS/ HANDS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
LOWER BACK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
HIPS/ THIGHS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
KNEES	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
ANKLES/ FEET	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes

Figure 1: Example of questionnaire to evaluate musculoskeletal disorders

2. Direct methods are based on collecting data directly from sensors attached to the worker's body. They can provide large quantities of highly accurate data on a range of exposure variables.

   Some examples of direct methods are: The Lumbar Motion Monitor (LMM), an electronic exoskeleton applied to the torso that records continuous data for three-dimensional components of trunk position, velocity and acceleration for subsequent analysis by computer, electronic goniometers, that provide continuous recordings of the movement across joints during the performance of a task, (Figure 2 shows an example of it), tri-axial accelerometers, have been developed that in combination with appropriate software, are suitable for the assessment of body postures and movements during whole-day ambulatory monitoring of occupational work, body posture scanning systems, record body posture that rely on the attachment of optical, sonic or electromagnetic markers to specific anatomic points on the worker and are used with corresponding scanning units to track the position and angular movement of different body segments, another direct method is the synchronous recording and computerized analysis of myoelectrical activity (EMG). This can be used to estimate muscle tension although the relationship may be non-linear in many circumstances, therefore a careful interpretation is required, and cyberGlove, that records wrist, hand and finger movements together with grip pressure directly online to a laptop computer. These examples of direct methods are shown in **¡Error! La autoreferencia al marcador no es válida.** [3].

However, they are difficult to implement in real work situations, and wearing sensors, may cause discomfort and influence the postural behavior.

Also, the enhanced data generation capacity of many of these systems may be considered impractical by many practitioners because of the time required for the analysis and interpretation of the data. Direct measurement systems require considerable initial investment to purchase the equipment, as well as the resources necessary to cover the costs of maintenance and the employment of highly trained and skilled technical staff to ensure their effective operation.

Table 1: Example of direct methods

Technique	Main features	Function
LMM	Triaxial electronic goniometer	Assessment of back posture and motion
Electronic goniometry	Single or dual plane electronic goniometers and torsiometers to record joint posture	Measurement of angular displacement of upper extremity postures
Inclinometers	Tri-axial accelerometers that record movement in two degrees of freedom with reference to the line of gravity	Measurement of postures and movement of the head, back and upper limbs
Body posture scanning systems	Optical, sonic or electromagnetic registration of markers on body segments	Measurements of displacements, velocities and accelerations of a body segment
EMG	Recording of myoelectrical activity from exercising muscles	Estimation of variation in muscle tension and force application
Force measurement	Computer mouse with sensors recording forces applied to side and button	Determination of finger force exposures
CyberGlove	Lightweight glove incorporating 22 motion sensors and Uniforce pressure sensors	Measurement of wrist, hand and finger motion with superimposed grip pressure

Figure 2: Example of electronic goniometry

3. Observational methods (OMs) are based on direct observation made by examiners, which collect the necessary data while observing the work carried out by the worker. After that, they use tables or equations to measure the risks related to ergonomics aspects of the tasks developed. This kind of methods are usually easy to use, applicable to a wide variety of work situations at a comparatively lower cost, where using other methods of observing workers would be difficult because of the disruption caused, and they are also suitable for many workers. They are more suited to the assessment of static or repetitive jobs. They determine scores of combinations of exposure factors with the aim of prescribing acceptable exposure limits for workers, or at least establishing priorities for intervention across a range of tasks. Besides, collecting postural information in real-time, as opposed to the analysis of videos, significantly reduces the time and effort associated with analysis.
   The more important observational methods are the RULA, REBA and OWAS methods.

2.3.- Ergonomic evaluation methods for the analysis of the postural load

This section describes the main methods of ergonomic evaluation for the analysis of postural load. These methods are RULA, REBA and OWAS. A comparison of the three methods is made and a summary of their limitations is subsequently made.

2.3.1.- RULA

One of the most popular observational methods is the RULA (Rapid Upper Lim Asseement), McAtamney and Corlett 1993 [4]. The examiner has to rate a static key posture of the worker based on real-time or videos and need to be trained to accurately fill in the RULA assessment grid.

RULA requires the observer to code either the posture held for the greatest duration, or the posture associated with the greatest loading, to identify whether or not non-neutral postures are present. As most observation methods used in the industry, it focuses primarily on the evaluation of static postures, mainly due to the lack of suitable human performance analysis tools available for dynamic motion. However, this method does not provide postural loading information for an entire job, job task or environmental variables.

The method of application of the RULA method is the following:

- Determine cycle times and observe the worker for several of these cycles
- Select the postures that will be evaluated
- Determining, for each position, if the left and right side or be evaluated (in case of doubt both will be assessed)
- Determine the scores for each body part
- Get the final score of the method and performance level to determine the risk stocks
- Check the scores of the different body parts to determine where you need to apply corrections
- Redesigning the post or changes to improve posture if necessary
- If you have made changes, reassess the position with RULA method to check the effectiveness of the improvement.

To begin using the method, the first thing we have to do is divide the body in two groups.

The first group, group A, includes, upper limbs, upper arm, lower arm, wrist twist and the second group, group B, includes neck, trunk and legs. Then, for the group A we must look at the position of the upper arm, lower arm and wrist twist and relate them to the drawings shown in Figure 3, thus providing a score to each part of the body. With the scores obtained, we enter in the Table 2 and obtain a provisional score for group A.

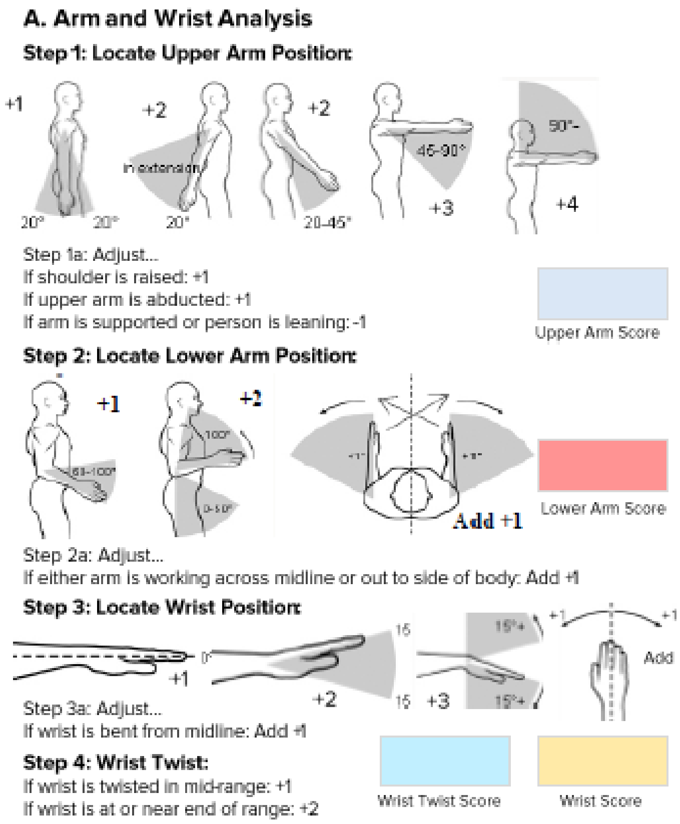


Figure 3. RULA method for group A

Table 2. RULA score for group A

Table A		Wrist Score							
		1		2		3		4	
Upper Arm	Lower Arm	Wrist Twist		Wrist Twist		Wrist Twist		Wrist Twist	
		1	2	1	2	1	2	1	2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Once obtained the provisional score of Table 2, we will add the partial scores if the posture is static or repetitive, or loads are used, thus the final score of group A, will be the sum of the score obtained from Table 2, plus the sum of the scores in the event that the posture is static or repetitive, or in the case where loads are involved, Figure 5.

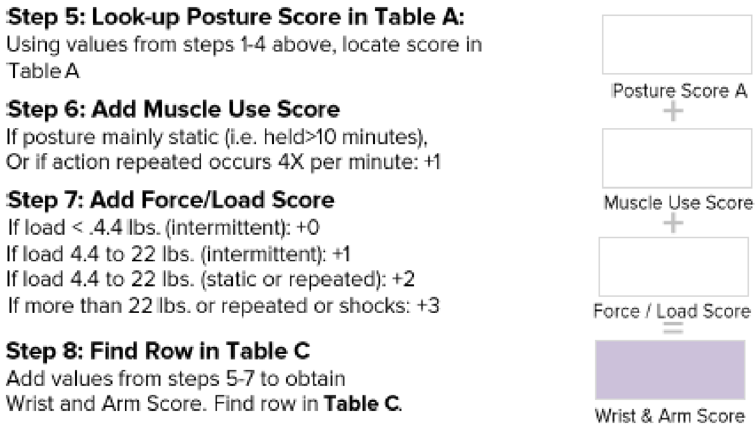


Figure 5: Final score of group A

For group B, we must follow the same steps as for group A. We will look at the positions of neck, trunk and legs, and relate them to the drawings shown in Figure 4. In this way we will obtain for each part of the body a score, that then we will relate in Table 3 to obtain the provisional score of group B.

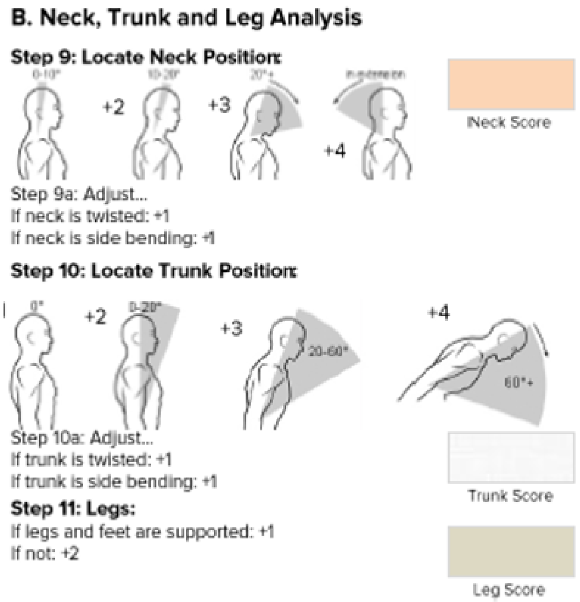


Figure 4: RULA method for group B

Table 3: RULA score for group B

Neck Posture Score	Table B: Trunk Posture Score											
	1		2		3		4		5		6	
	Legs		Legs		Legs		Legs		Legs		Legs	
	1	2	1	2	1	2	1	2	1	2	1	2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

As for the group A, in case the posture is static or repetitive, or loads are used, we will sum them to the score obtained in Table 3, resulting this sum, the final score of group B, Figure 6.

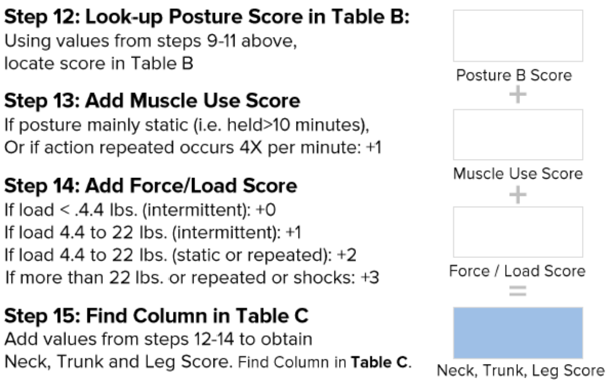


Figure 6: Final score of group B

With the final score of group A and B, we enter in Table 4 and obtain the final score for the RULA method.

Table 4: Final score of the RULA method

Table C		Neck, Trunk, Leg Score						
		1	2	3	4	5	6	7+
Wrist / Arm Score	1	1	2	3	3	4	5	5
	2	2	2	3	4	4	5	5
	3	3	3	3	4	4	5	6
	4	3	3	3	4	5	6	6
	5	4	4	4	5	6	7	7
	6	4	4	5	6	6	7	7
	7	5	5	6	6	7	7	7
	8+	5	5	6	7	7	7	7

The level of exposure and investigation priorities are classified as acceptable posture if not maintained or repeated for long periods (1 or 2 points); more investigations are needed and changes may be required (3 or 4 points); investigation and changes are required soon (5 or 6 points); investigation and changes are required immediately (7 points), Figure 7.

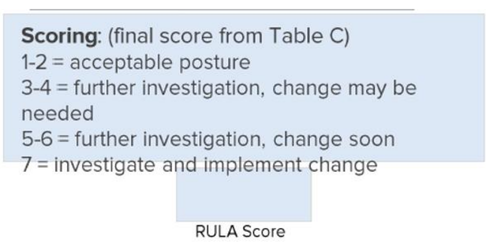


Figure 7: Meaning of the final score of the RULA method

The advantages of this method is that it was designed to be carried out quickly and with minimal equipment or change to the working environment, and with minimal disruption to those under observation, and it does not require no previous skills in observation techniques and is easy to learn [5].

2.3.2.- REBA

Rapid Entire Body Assessment (REBA) is a method developed by Dr Sue Hignett and Dr Lynn McAtamney (2000) in the UK, applied to analyze risk postures of whole body segments: neck, trunk, legs, arms and wrists. It differs from the RULA method in the parts of the body that we must evaluate and in the system of assessing risk.

REBA method provides a quick and easy measure to assess a variety of working postures for risk of Work-Related Musculoskeletal Disorders (WMSDs). It is a worksheet used to assess entire body movements during performing tasks.

We must follow the same steps as for the RULA method, with the difference that the final score of the REBA method is the sum of the group A that includes the trunk, neck and legs, and the group B, that includes the upper arms, lower arms and wrists.

For group A we will observe the postures adopted by each part of the body and relate them with the drawings shown in Figure 8, providing each of them with a score.

With these scores, we will enter in Table 5 and obtain the score of the REBA method for group A, to which we will add, in case there are loads, a partial score as shown in Figure 8, step 5. This group has a total of 60 posture combinations for the trunk, neck and legs, which reduces to nine possible scores to which a “Load/Force” score is added [6].

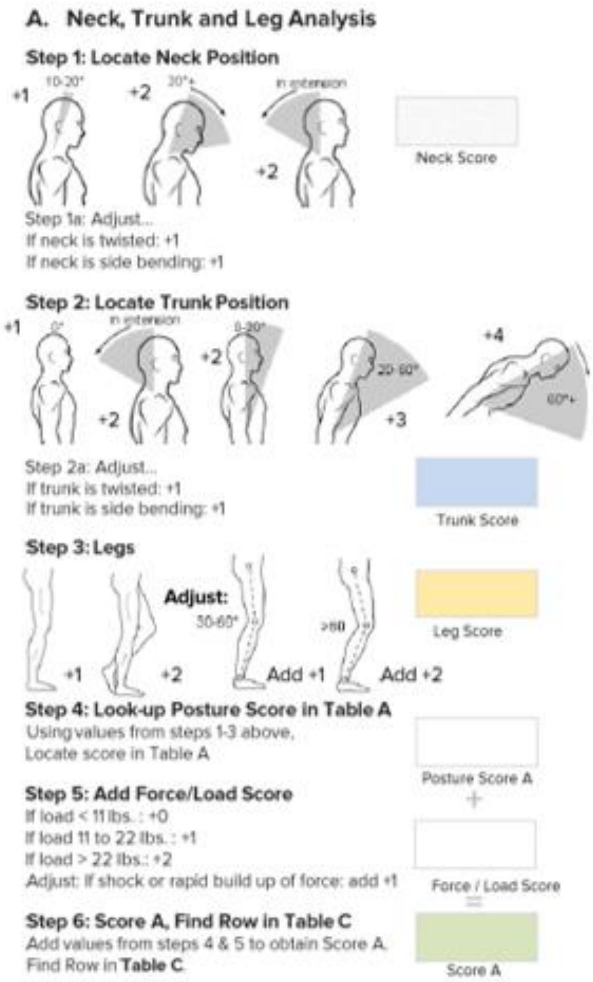


Figure 8: REBA method for group A

Table 5: REBA score for group A

Table A		Neck											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

On the other hand, we will do the same for group B by observing the positions that the upper arms, lower arms and wrists assume, Figure 9, providing each of them with a score, and transferring these scores to Table 6 to obtain the score of the REBA method for group B, to which a "Coupling" score is added, Figure 9, step 11.

Group B has a total of 36 posture combinations, reducing to nine possible scores, not including the “Coupling” score.

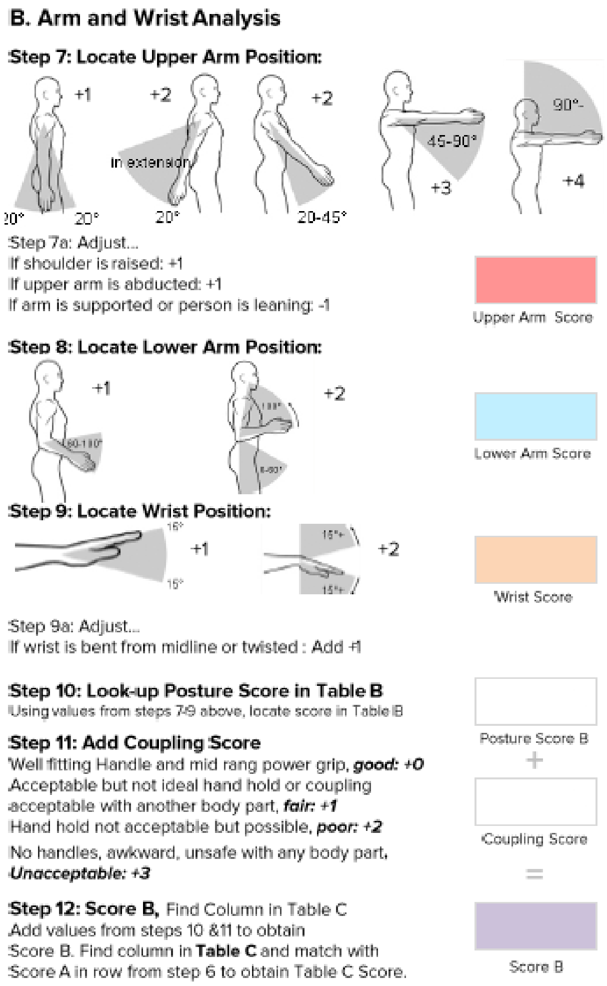


Figure 9: REBA method for group B

Table 6: REBA score for group B

Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

The A and B scores are combined in Table 7, to give a total of 144 possible combinations.

Table 7: Combination of the scores of groups A and B

Score A	Table C											
	Score B											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Finally, an activity score, that describes any static postures held for longer than 1 minute and a repetition more than 4 times per minute or large rapid changes in postures, or an unstable base, is added to give the final REBA score. Depending on the score obtained, we define whether action is required and its urgency, Figure 10.

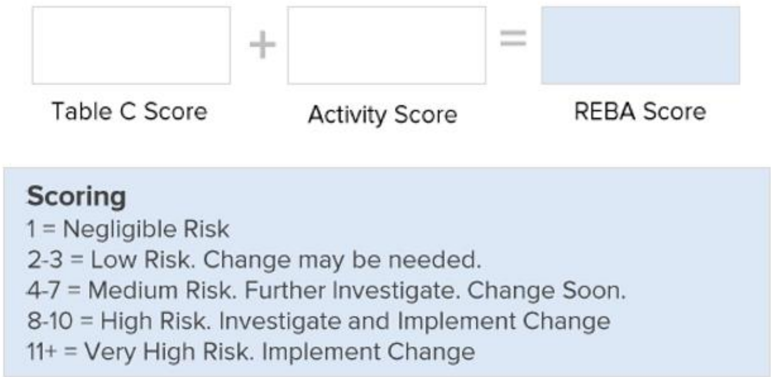


Figure 10: Final score of the REBA method and meaning of it

2.3.3.- OWAS

The Ovako Working Posture Analysis System (OWAS) work assessment tool, was first reported by Karhu, Kansi, and Kuorinka when evaluating ergonomic posture-related risk factors among Finnish steel mill workers. Since that time OWAS has been used in several industries [7].

It is a practical method for identifying and evaluating poor working postures, which consists of two parts.

The first, consists in an observational technique for evaluating working postures, used by work-study engineers in their daily routine and it gives reliable results after a short training period.

The second part of the method is a set of criteria for the redesign of working methods and places. The criteria are based on evaluations made by experienced workers and ergonomics experts. They take into consideration factors such as health and safety, but the main emphasis is placed on the discomfort caused by the working postures. [8]

The method identifies the positions of the back, shoulders and legs of the worker and the weight of the load handled. The evaluator makes observations at regular intervals of 30-60s coding each posture according to the digits shown in Figure 11, and an additional fourth digit depending on the load handled by the worker.

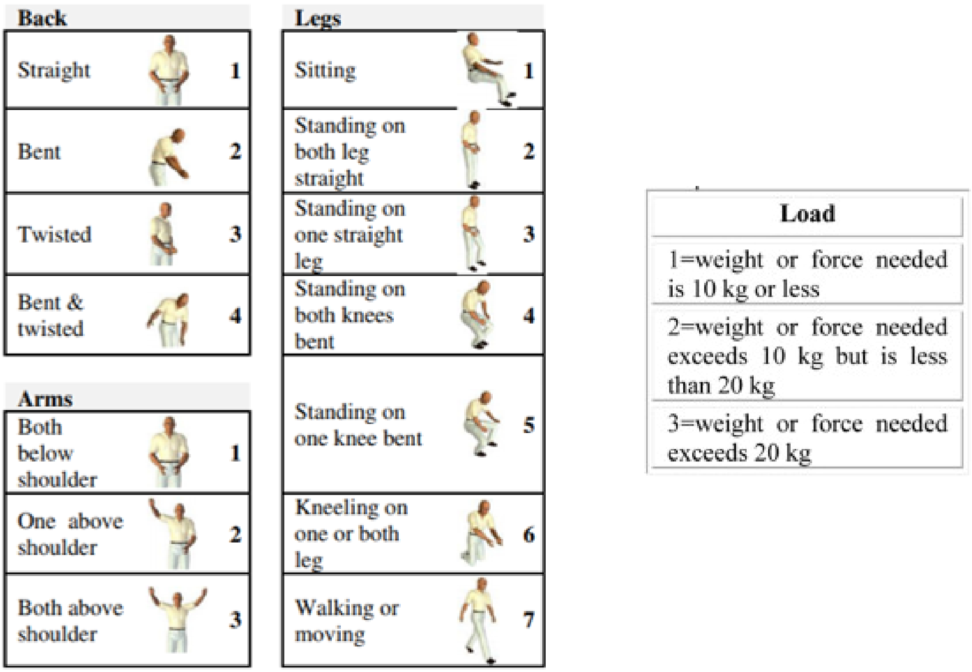


Figure 11: Definition of codes for back, arms, legs and load in the OWAS method

Based on the body position, the OWAS method, identifies four classes which reflect static load risk degree, Table 8.

- Class 1: Normal posture. No intervention required.
- Class 2: Slightly harmful. Corrective action should be taken during next regular review of working methods.
- Class 3: Distinctly harmful. Corrective action should be taken as soon as possible.
- Class 4: Extremely harmful. Corrective action should be taken immediately.

The real proportion of time in each posture is estimated from the observed postures. Therefore, the estimation error decreases as the total number of observations increases. The limit for this error (with 95% probability) based on 100 observations is 10%. The error limits based on 200, 300 and 400 observations are 7%, 6% and 5% respectively. The values obtained through observations can be considered reliable when the error limit is below 10% [9].

Table 8: Classes which reflect static load risk degree according to OWAS

Back	Arms	1			2			3			4			5			6			7			Legs
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	Load Handled
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2	
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3	
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	4	4	3	3	4	2	3	4	
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4	
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1	
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1	
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1	
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4	
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	

2.3.4.- Comparison between RULA, REBA and OWAS

Different aspects are compared in Table 9 and their variations are shown according to the chosen method.

The main differences between the three methods are: the target exposures and dimensions, while in the REBA and OWAS methods the posture and the force are evaluated, in the RULA method, we also have to add the static action. The other main difference is the field of applications. As shown in Table 9, the RULA method is applied to the upper limb assessment, the REBA method to the upper limb assessment and legs, and the OWAS method to the whole body.

On the other hand, the limitations are: for the RULA method, the impossibility of evaluating at the same time the left and right hand and not considering the duration of exposures. As in the RULA method, for REBA, the right and left hand have to be assessed separately. Besides, the user has to decide in which posture base the method, if in the most common posture, most prolonged or in the most loaded posture. It also does not include the duration and frequency of items.

The OWAS method, however does not separate right and left upper extremities, does not include assessments of neck and elbows/wrists, does not consider repetition or duration of the sequential postures, and a lot of time is lost in relation to the other two methods.

Table 9: Comparison between RULA, REBA and OWAS.

	RULA	**REBA**	**OWAS**
Target exposures and dimensions	Posture, force and static action	Posture, force	Posture, force
Metrics	Sum score of weighted items	Sum score of weighted items	Frequency of items
Observation strategy	No detailed rules	Most common/ prolonged/loaded/ postures	Time sampling
Field of applications	Upper limb assessment	Upper limb assessment and legs	Whole body posture analysis
Mode of recording	Pen & paper, video	Pen & paper	Pen & paper, computerized
Correspondence with 'valid' reference	Low-moderate	Moderate	Moderate
Strengths	Easy to use. Computerized registration available in public domain.	Rapid to use. Computerized registration available in public domain.	Widely used and documented
Limitations	Right and left hands have to be assessed separately but there is no method available to combine these scores. Does not consider duration of exposures.	Right and left hand have to be assessed separately and there is no method to combine this data; the user has to decide what to observe. Duration and frequency of items not included	Does not separate right and left upper extremities. Assessments of neck and elbows/wrists are missing. Time-consuming. Does not consider repetition or duration of the sequential postures
Potential users	Occupational safety/health practioners/ergono mists Researches	Occupational safety/health practioners/ergono mists Researches	Researches

2.3.5.- Limitation in the use of OMs

Despite its low cost, easy utility and applicable to a wide variety of work situations, observational methods have some limitations.

As disadvantages, it should be noted that the accuracy and validity of the results obtained depend directly on the input information collected, which this information is generally obtained by subjective observation or simple estimation of projected angles in videos/pictures. This leads to low accuracy and high intra- and inter-observer variability.

Thus, a certain level of experience and knowledge for their proper use is needed. For example, it is necessary to know what risk factor is being assessed and the particular conditions of the task under analysis for the correct selection of the most suitable assessment method. Moreover, knowledge about the degree of accuracy and reliability of the selected method and ability to correctly interpret the results are needed.

Many countries' current regulations do not guarantee that examiners have the necessary qualifications to properly apply OMs. For example, the legislation of many European and American countries does not demand of companies that people responsible for carrying out risk assessments have specific training or qualifications. In some cases, the only requirement is to possess very basic training. Therefore, in many cases the examiners do not have the necessary training recommended for the correct use of ergonomics analysis tools or to correctly interpret the results obtained from their use [10].

The criteria for determining the optimum number of observations for low and high repetitive tasks are still unclear, and one important limitation of most posture-based observation techniques is that factors such as load/force, repetition and duration of movement, vibration, as well as psychosocial and individual factors are not simultaneously considered in the assessment process.

2.4.- Legislation

There are a series of standards in the field of engineering and the development of new products, focused on ergonomic aspects, to perform the correct sizing of products. Below is summarized the UNE-EN 1729 part 1 and part 2. It is the main norm that governs the characteristics, dimensions and safety requirements that chairs and tables must have for educational use.

This norm is the Spanish version of the European norm EN 1729-1: 2006. It is a norm that must be met by the manufacturers of school furniture and with which the ergonomics and well-being of the students are pursued.

Customers must request their suppliers the presentation of the appropriate certifications in order to guarantee the safety of the product.

- **UNE-EN 1729-1:2015 Furniture - Chairs and tables for educational institutions – Part 1: Functional dimensions**

The norm does not specify the design of the chairs or tables destined to the educational institutions, but the necessary dimensions to obtain the correct postures of the users.

Below are the main characteristics and dimensions by which we will be governed, for a chair with an inclination seat between -5º and +7º:

a) All accessible edges must be rounded or beveled.
b) The seat must have enough space so that the buttocks can move freely, as illustrated in the Figure 14.
c) Edges and raised surfaces should not dig into the thighs. This requirement is met when these points are at a height less than 15 mm above the lowest point of the seat surface, Figure 12.

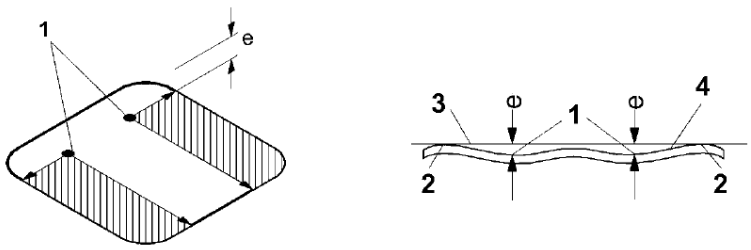


Figure 12: Raised seat edges

The key dimensions are shown in Figure 13, Figure 14 and Figure 15 to make the correct design of the chair.

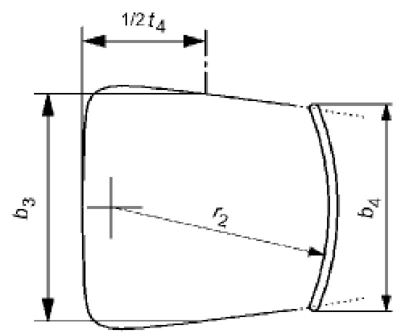


Figure 13: Key dimensions of a chair (plan view)

Legend:

- b_3 Seat width
- b_4 Backrest width
- r_2 Horizontal backrest radius
- t_4 Useful depth of the seat

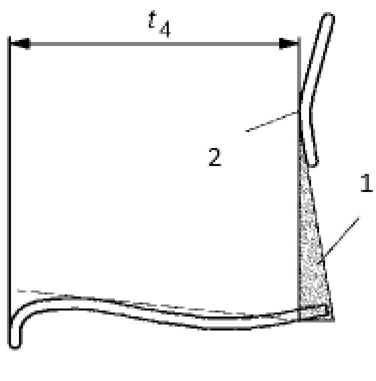


Figure 14: Key dimensions of a chair (profile view) and breech area (shaded area)

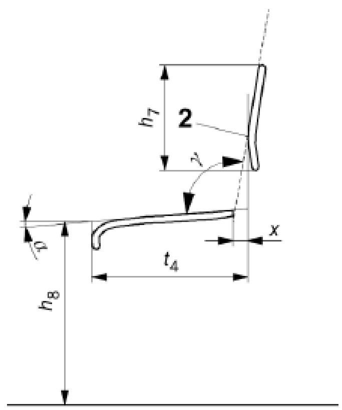


Figure 15: Key dimensions of a chair with positive seat tilt angle

Legend:

- 2 Point S
- α inclination of a single tilting seat
- γ Angle between the seat and the backrest
- h_7 Backrest height
- h_8 Seat height
- x Distance between point S and the back of the seat

Table 10 shows the dimensions that must be adopted for the correct design of the chair.

Table 10: Dimensions of chairs with single tilt seats in mm

Chair size mark	**5**	**6**	**7**
Range of height (without shoe)	1460-1765	1590-1880	1740-2070
h_8 Seat height ±10	430	460	510
t_4 Useful depth of the seat ±15 (0-2), ±25 (3-7)	380	420	460
b_3 Seat width (minimum)	360	380	400
x Distance between point S and the back of the seat	50	50	50
h_7 Backrest height (minimum)	100	100	100
b_4 Backrest width (minimum)	300	330	360
r_2 Horizontal backrest radius (minimum)	300	300	300
α Tilt of the seat	-5° a +7°	-5° a +7°	-5° a +7°
γ Angle between the seat and the backrest	95 ° a 110 °	95 ° a 110 °	95 ° a 110 °

- **<u>UNI-EN 1729-2:2006 Furniture - Chairs and tables for educational institutions – Part 2: Safety requirements and test methods</u>**

This part of EN 1729 specifies safety requirements and test methods for chair and tables for general educational purposes in educational institutions.

In order to minimize the risk of personal injury or damage to clothing, we must follow the following requirements.

a) Edges of the seat, back rest and arm rest, which are in contact with the user when sitting in the chair shall be rounded with a minimum 2mm radius
b) All other edges and corners with which the user may come into contact with during normal use shall be smooth, rounded or chamfered and shall have no burrs
c) Open ends and feet of tubular components shall be capped or otherwise closed
d) Parts shall not be detachable without the use of an appropriate tool
e) Parts which are lubricated shall be covered in order to avoid staining
f) Chairs shall not overturn when tested as specified in the section 'Testing of chairs'

Testing of chairs

Below are described several methods to which we must subject the chair to ensure the correct design of it.

<u>Forward and sideways stability of chairs</u>

Figure 16 and Figure 17 show the position where the load should be applied, and

Table 11 the load that must be exercised on the chair depending on its size.

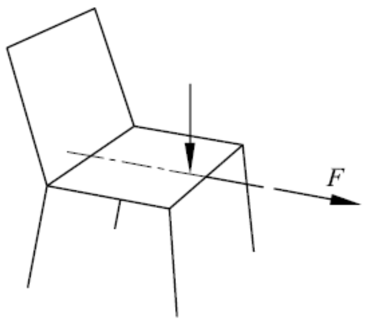


Figure 16. Forward stability of chairs

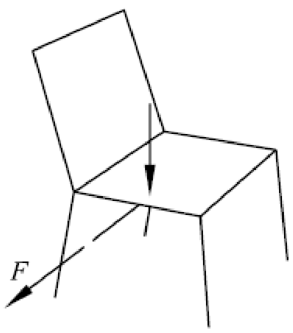


Figure 17. Sideways stability of chairs

Table 11: Forward and sideways stability

Chair size mark	Seat load [N]	Horizontal force [N]
5	600	20
6	600	20
7	600	20

Rewards stability of chairs

Figure 18 show the position where the load should be applied, and Table 12 the load that must be exercised and its position on the chair depending on its size.

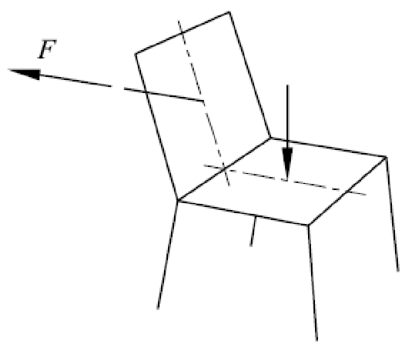


Figure 18: Rewards stability of chairs

Table 12: Rearwards stability of chairs

Chair size mark	Seat load [N]	Point S to seat loading point [mm]	Seat to back loading point [mm]	Back force [N]
5	600	175	300	180
6	600	185	300	180
7	600	185	300	180

<u>Seat and back static load</u>

Figure 19 show the position where the load should be applied, and Table 13 the load and number of exercises that must be exercised on the chair depending on its size.

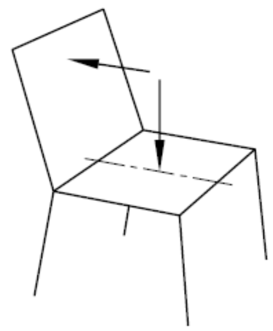


Figure 19: Seat and back static load

Table 13: Seat and back static load chairs

Chair size mark	Cycles	Seat load [N]	Back load [N]
5	10	2000	Max 700
6	10	2000	Max 700
7	10	2000	Max 700

3.- State of the art about ergonomic chairs and seats

This chapter includes a section which describes how the ergonomic aspects vary according to the type of seat, a summary with the different types of patented chairs that can be found in a lecture room and finally the market analysis to which our product is directed.

3.1.- Ergonomics in different types of seats

We do not have to take into account the same ergonomic parameters for different seat type, since each of them is designed with a very different objective. Therefore, we will list some examples of chairs/seats, with their corresponding ergonomic parameters in which we will have to focus for their design.

These examples were taken from research works, patents and other studies that described the characteristics of each one. We chose three random types of seats with the objective when choosing, that were seats used in very different environments and whose dimensions and characteristics were quite diverse to better observe the different ergonomic parameters of each.

3.1.1.- Armchair of a train

We will take as an example an armchair of the 'Trenhotel', which is a high end service offered by RENFE for passengers to rest or sleep comfortably during night routes, Figure 20.

Figure 20: Armchair of the 'Trenhotel'

The comfort of these seats acquires a crucial importance, since the main objective is to make the journey a relaxed experience for the passenger.

Ergonomic parameters to have in consideration:

1. Adapt the dimensions of the seats to the measures of the Spanish population, since in this case, all the journeys of 'Trenhotel', have as their origin or destination capitals of Spain.
2. Adaptation to 'normal' and 'super-relax' positions, main uses of the armchair. Seated or 'normal' position for activities such as eating, reading, watching movies... or reclining or 'super-relax' position to rest or sleep, Figure 21.

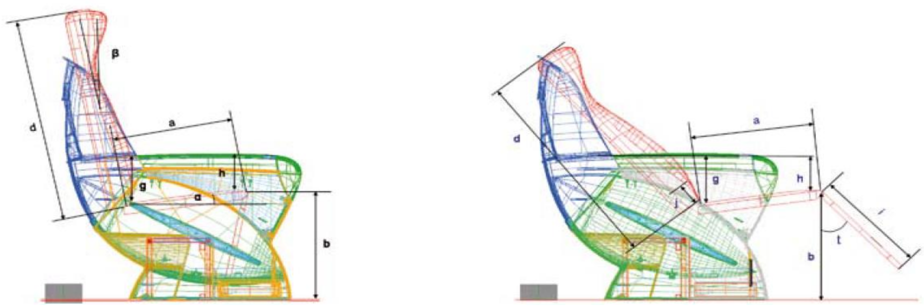


Figure 21: 'normal' and 'super-relax' positions [11]

In the 'super-relax' position muscle and spinal tension are increased. To minimize this risk, we must adjust the recline level of the seat.

3. The support of the different parts of the body on the elements of the chair, the floor and other points must be complete, both for the elderly and for the little ones.
4. Avoid gaps too narrow for the larger people
5. Resistance and security. The seats are frequently manipulated and can be subjected to great stress; therefore, they need to be robust and resistant, both the structure and the exterior finish. Safety and accident prevention are closely related to this aspect. To meet all these requirements, in addition to using appropriate materials, it is convenient to minimize the number of mechanisms and moving parts to the strictly necessary to fulfil the comfort functions effectively.

3.1.2.- Sofas

Until recently, in the domestic furniture market, the style, appearance and quality of materials have been the main arguments of sale and purchase, leaving aside the ergonomic values.

This has been changing over the years, and domestic furniture, in this case the sofa, has been improving its ergonomic aspects, improving comfort, functionality...

Ergonomic parameters to have in consideration:

1. Sofa sizes: Not all buyers have the same anthropometric characteristics, therefore sofas must be designed with different measures. An example would be the manufacture of a 'Young' size, suitable for buyers and users aged around 20-30 years, clearly higher than users of the size 'Classic', people around 45-50 years.
2. Factors that affect comfort and favour the adoption of appropriate postures, such as seat heights, depths, seat-back angle combinations, ease of use of regulations, etc.

3. If the sofa presents "living" corners, edges and sharp edges, it can cause minor accidents to users, such as cuts and bruises. Accidents to get up or sit due to anthropometric inadequacies should also be considered and avoided.
4. The stability is also an essential feature of the product in order to avoid physical damage and imbalances of the users.
5. Landfill of the sofa. It is important that it is of high density and that it is breathable [12].

Figure 22: Example of ergonomic sofa

3.1.3.- Study chairs for children

It is very important, when buying a study chair for a child, to focus in its ergonomic aspects, to increase the efficiency in the study and avoid pain due to the bad postures adopted. We will focus in the following ergonomic parameters:

1. Backrest for the lower back
2. They must be firm but avoiding excessive hardness.
3. The height of the working chair depends on the anthropometric characteristics of the child. The best way to adapt the chair is through a chair that has the height of the seat and the backrest adjustable.
4. It is not necessary to have armrests, since sometimes they make the coupling to the table more difficult.
5. The seat must be wide so that it allows changes in the sitting position [13].

Figure 23: Example of a study chair for children

3.2.- Patents

Nowadays, there is a wide variety of chairs for the lecture room. They can be with a table incorporated to the chair itself, fixed to the floor without the possibility of regulating the distance from the chair to the table, with a grid under the seat...

Below, is listed a series of chairs with very different characteristics that have been patented for its use in the lecture room.

Those references were considered:

- A47C1/121 Theatre, auditorium, or similar chairs having tipping-up seats.
- A47C3/04 Stackable chairs; Nesting chairs.
- A47C7/002 Chair or stool bases.
- A47B41/02 Adjustable, inclinable, sliding or foldable desks tops.
- A47C7/441 Support for the head or the back for the back with elastically-mounted back-rest or backrest-seat unit in the base frame with adjustable elasticity.
- A47C7/443 Support for the head or the back for the back with elastically-mounted back-rest or backrest-seat unit in the base frame with coil springs.
- A47C7/445 Support for the head or the back for the back with elastically-mounted back-rest or backrest-seat unit in the base frame with leaf springs.

Combined chair and desk

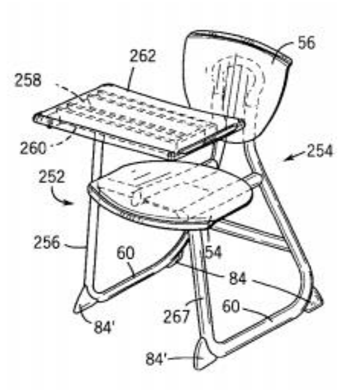


Figure 24: Chair and desk system; Patent number US 6,604,784 B1

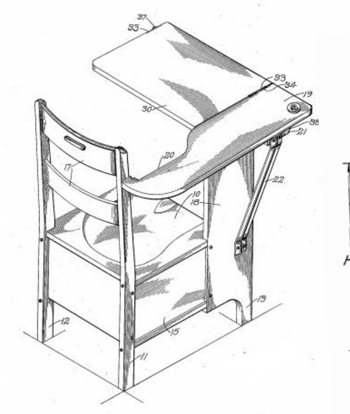


Figure 26: Chair Desk. Patent number: 536,033.

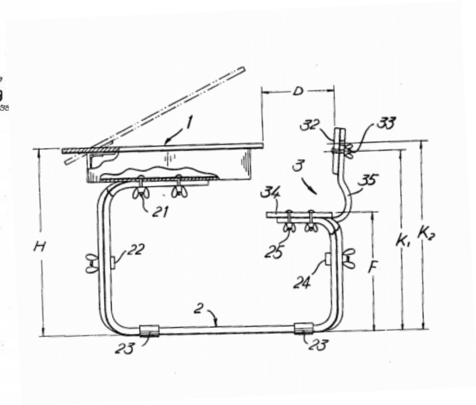


Figure 25: Adjustable desk and chair combination. Patent number: 884,465

This type of chairs are not the most suitable for students due to the limited space that has the desk. In addition, they do not have easy accessibility and are not adaptable to the different statures of each person. Each of these furniture needs a lot of space, so it would not be possible to use it for classrooms with many students.

Chair without armrest

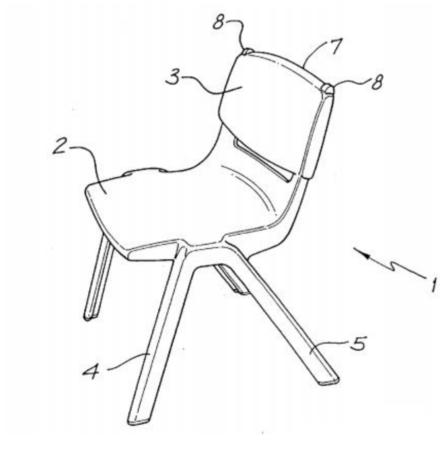


Figure 27: School chair; Patent number: 5,860,697

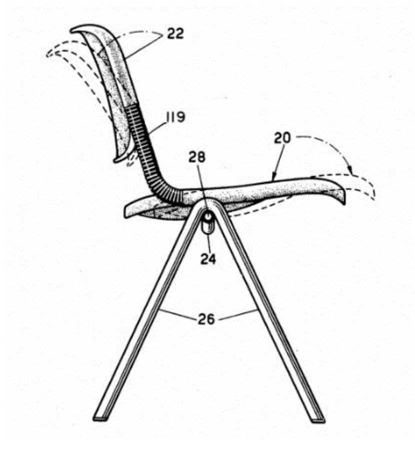


Figure 28: Chair. Patent number: 4,084,850

The simple design of this type of chairs makes it possible to adapt better to a greater number of people, they also have good accessibility. They are stackable, in case they are not needed they take up less storage space.

<u>Theatre seat</u>

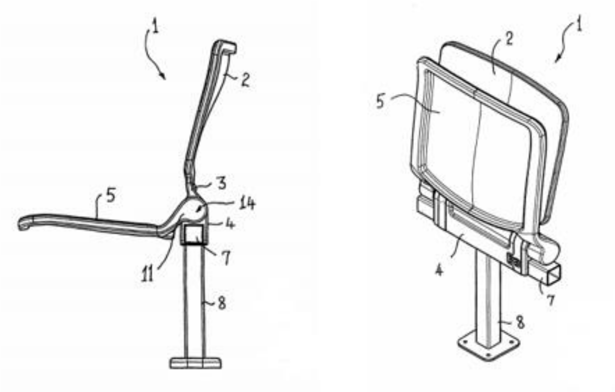


Figure 30: Theatre seat. Patent number

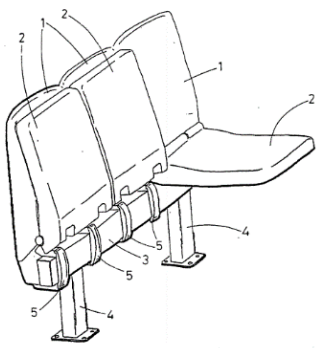


Figure 29: Chair with collapsible seat.
Patent number: EP 1 166 683 B1

This kind of chairs are locked to the floor which facilitates the lecture room to be orderly. It also optimizes the available space. The collapsible seat facilitates the accessibility.

Within this classification can also be found with armrests. Such as:

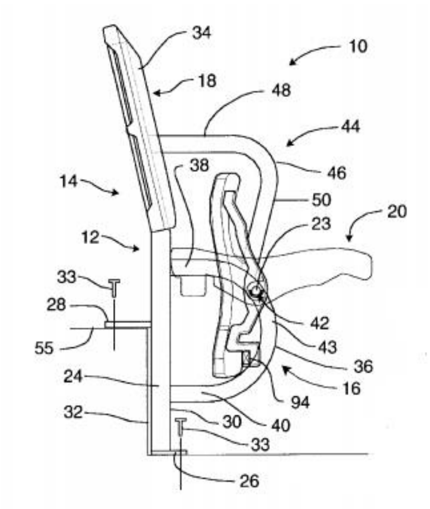


Figure 32: Gravity lift chair. Patent number:
US 6,293,621 B1.

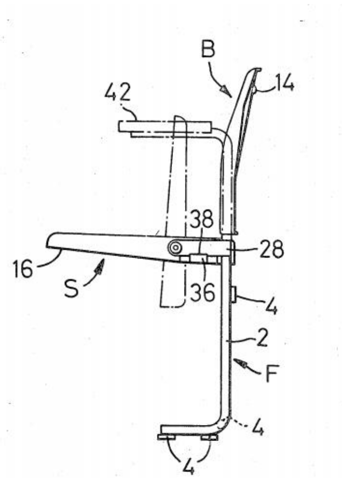


Figure 31: Tp-Up Seating. Patent number:
3,850,476

Table 14: Advantages and disadvantages of different types of chairs

Type of chair	Advantages	Disadvantages
Combined chair and desk	Personal workspace	Limited space in the desk Large dimensions Access and exit is not completely free
Chair without armrest	Can be easily stacked Possibility of regulating the distance between the desk and the chair Good accessibility	Messier lecture room Cause noise when moving
Theatre seat	Lecture room ordered The collapsible seat facilitates the accessibility Small dimensions	Impossibility to regulate the distance between chair and desk

Within the categories previously described, the category that has the most disadvantages is the combined chair and desk, within these, the most important is the large dimensions of the furniture, since large classrooms would be needed. On the contrary, the work of space is personal and the chair adapts better to the anthropometric characteristics of each person since it allows to regulate the distance between the chair and the table.

Unlike the previous category, with the chairs without armrests it is possible to regulate the distance from the chair to the desk. By being able to move them easily they can be stacked which would save a lot of space if they are not used, they also have an easy accessibility. As a disadvantage, this freedom of movement causes a lot of noise and disorder in the classroom.

Once reviewed the different types of chair it is concluded that the chair which gathers the best characteristics for its use in the lecture room is the “Theatre seat” since has a good accessibility to the seat, it optimizes the available space and allows the lecture room to be ordered.

3.3.- Market analysis

This section aims to show the commercial viability of our project. For that, we will determine the geographic area in which we will focus and describe the potential market into which we are heading.

The chairs will be marketed in Italy, in particular will have as a target market all public universities in Italy.

To start, it will be marketed at the University of Parma, which currently has 22,504 students, and the market will then be extended to the 76 public universities that exist nowadays in Italy.

The volume of chairs to market, will be estimated one chair for every two students, so in the case of the University of Parma will require 11,252 chairs.

Purchase Motivations: Due to the improvements that are intended to be made in the chair in both ergonomic and aesthetic aspects, it is expected that the buyer will opt for the purchase of this chair.

4.- Method for the ergonomic design of a classroom chair

This chapter includes the flowchart that we will follow to make the design of the new chair, including the descriptions of each step. The design of a new chair will be divided into four well-differentiated blocks, a subsequent cost section, and finally a comparative section between the old and the new chair. These four blocks are: Reverse engineering for ergonomics, ergonomics assessment, ergonomics issues identification and ergonomics redesign.

Following the steps marked according to the flowchart we will be able to design a new more ergonomic chair.

4.1.- Method flowchart

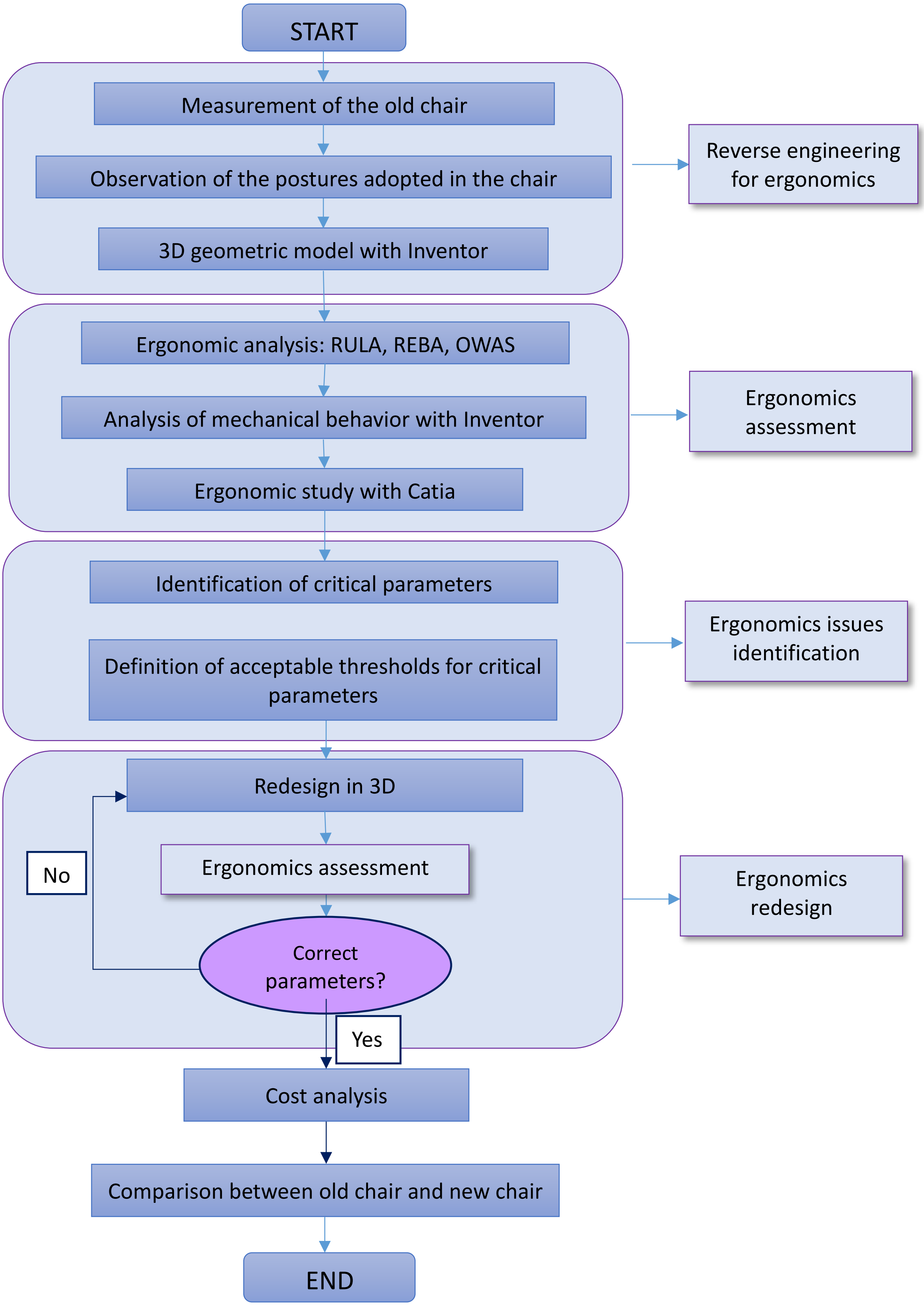
The flowchart method includes a structured workflow that can be followed to completely redesign the chairs used in the school environment, both in schools and universities.

This flowchart is divided into four well-differentiated blocks: reverse engineering for ergonomics, ergonomics assessment, ergonomics issues identification and ergonomics redesign.

Subsequently, there is a decision-making process (yes / no) that evaluates whether the changes made in the new chair meet the desired parameters or not.

Then, through a cost analysis, the economic part of the redesign actions implemented is evaluated.

To finalize a comparison between the old and the new chair is made in which the ergonomic improvements made are seen.


START
Measurement of the old chair
Observation of the postures adopted in the chair
3D geometric model with Inventor
Reverse engineering for ergonomics
Ergonomic analysis: RULA, REBA, OWAS
Analysis of mechanical behavior with Inventor
Ergonomic study with Catia
Ergonomics assessment
Identification of critical parameters
Definition of acceptable thresholds for critical parameters
Ergonomics issues identification
Redesign in 3D
Ergonomics assessment
Correct parameters?
No
Yes
Ergonomics redesign
Cost analysis
Comparison between old chair and new chair
END

4.2.- Detail description of the method

Starting from the flowchart proposed in the previous paragraph, here below are described, in details, the steps necessary to perform the proposed methodology. The method is general and can be applied to any chair or seats for educational purposes.

4.2.1.- Reverse engineering for ergonomics

To begin the design of a new chair, we start by analyzing the old one, so we start measuring the old chair, observing the postures that users adopt in it, and making a 3D geometric model with the Inventor program.

- <u>Measurement of the old chair</u>

The work starts with a measurement of the dimensions of the chair that will be redesigned.

All the necessary measures of the chair (seat, backrest, legs, restraints ...) will be taken with the help of a meter. These measurements will be necessary to be able to subsequently make the modeling of it in 3D.

We will also measure the table, as well as the distance between the chair and the table, since this distance also influences the different positions that the user adopts, influencing the ergonomic aspects.

The minimum measures that we must measure in a chair are:

  - Height and width of the seat
  - Height and width of the backrest
  - Height of the leg

- <u>Observation of the postures adopted in the chair</u>

In the chair previously used to take the measurements, an observation process is made of the different postures adopted by a user. The chosen user adapts to the average anthropometric measurements of Italian university students, and the observation process is performed when the user adopts a working posture in the classroom.

A series of photographs of each position is taken, to later analyse them more thoroughly, through the methods of ergonomic evaluation for the analysis of postural load.

For a correct analysis of the positions adopted by the user, three main positions must be observed:

- Posture adopted by the user for the longest period of time.
- Posture that most affects to get discomfort or musculoskeletal diseases.
- Position that the user should adopt by adapting his body to the shape of the chair.

- <u>3D geometric model with Inventor</u>

With the measurements obtained in the first section, a modeling of the 3D chair is made using Inventor program. First, each piece that contains the chair is made separately, adding materials to each component, and later with the assembly option that Inventor has, a 3D model of the study chair is obtained. From the same program are made, the plans of each piece, and the overall drawing of the chair.

4.2.2.- Ergonomics assessment

This block includes an ergonomic analysis using the RULA, REBA and OWAS methods, an analysis of the mechanical behaviour of the old chair with Inventor, and finally an ergonomic study with Catia.

- <u>Ergonomic analysis: RULA, REBA, OWAS</u>

An analysis of the postural load is carried out using the methods of RULA, REBA and OWAS.

With these methods the postures of previously taken photographs are analysed, to evaluate if the position adopted in the chair is the correct one or not, and in case of not being it, to be able to take the opportune measures to correct it.

Finally, in a table, the results obtained by the three methods are compared.

- <u>Analysis of mechanical behaviour with Inventor</u>

The Inventor program offers a module of tension analysis where a mechanical analysis of the chair modeled is performed, applying forces in a position and with certain loads according to the UNI-EN 1729-2: 2006 norm. The output are a series of graphs in which the response of the chair to these loads are analysed to check their resistance.

For a correct analysis of the mechanical behaviour of the chair we must obtain three parameters:

  ◦ Von Mises tensions
  ◦ Deformations
  ◦ Displacement

- <u>Ergonomic study with Catia</u>

Ergonomics and comfort studies are carried out with the Ergonomic Design and Analysis module. This module of Catia V5 is a tool that allows to check the ergonomic requirements of any product. This module is divided into four sub-modules:

  ◦ Human Measurement Editor: Allows the detailed creation of mannequins that can vary up to 103 anthropometric variables to get the exact mannequin desired by the user.
  ◦ Human Activity Analysis: It shows how a human being interacts with the objects in their work environment, such as lifting, lowering, pushing and pulling loads.
  ◦ Human Builder: In this module you will find the necessary tools for the generation of standard mannequins, specifying gender, percentile and nationality.
  ◦ Human Posture Analysis: This module allows to vary and examine the positions that the previously created mannequin adopts. Among the various analyses included in this module, the RULA method allows to obtain a score that indicates the risk that the mannequin takes when adopting such position.

4.2.3.- Ergonomics issues identification

After analysing the old chair, the critical parameters are determined on which it is necessary to base the design of a new chair, as well as the definition of acceptable thresholds for them.

- Identification of critical parameters

The parameters are identified in which we will have to look to make a correct design of the chair in order that the user adopts a correct posture in it.

  - Seat height
  - Seat width
  - Angle between thighs and trunk
  - Free space or curvature in the seat
  - Position of the arms with respect to the trunk
  - All edges must be rounded

- Definition of acceptable thresholds for critical parameters

Below are described the limit values that the previously defined parameters must take.

  - Seat height → The feet should always rest on the floor
  - Seat width → Minimum 400 mm
  - Angle between thighs and trunk → Equal to or greater than 90 degrees
  - Free space or curvature in the seat → Enough to accommodate the curvature of the gluteal region
  - Position of the arms with respect to the trunk → Should not exceed 30 or 40 degrees
  - All edges must be rounded → With a minimum radius of 2 mm

4.2.4.- Ergonomics redesign

This block includes the redesign of the new chair in 3D with Inventor, an ergonomic analysis using the RULA, REBA and OWAS methods, an analysis of the mechanical behaviour with Inventor, and finally an ergonomic study with Catia. If the values obtained in these analyses are within the acceptable values previously defined for the critical parameters, a cost analysis is carried out. Otherwise, the redesign of the chair is carried out again.

- Redesign in 3D

A redesign of the chair is done with the Inventor program, changing the dimensions of the old one, based on the results obtained from the RULA, REBA and OWAS methods, and on the critical parameters that we have to take into account so that the user adopts a better posture in the new chair. A 3D model of the new chair is obtained, and the planes of each piece, and the plane of the chair assembly are made.

- Ergonomics assessment

We will repeat the tasks of: ergonomic analysis with the RULA, REBA and OWAS methods, analysis of mechanical behaviour and ergonomic study with Catia previously described, with the difference that this time we will do them in the new chair.

The purpose of this additional analysis, in addition to verifying the calculations made previously with the 3 methodologies, allows more accurate information considering the real mannequins and their interaction with the bench-chair system.

- Correct parameters?

From the results obtained in block 1, it is checked whether the new chair is resistant to the loads applied (data obtained from the analysis of mechanical behaviour with Inventor) and if the positions adopted by the users in the new chair (data obtained from the methods RULA, REBA and OWAS), and the results obtained from the ergonomic study with Catia are the correct ones. If all the results are correct, continue with the following tasks. Otherwise, it goes back to the 3D redesign process.

4.2.5.- Cost analysis

A cost analysis of the designed chair is performed.

A study is made of the cost that would be involved in the manufacture of the new chair. Both the costs of materials, manufacturing of each of the components, assembly and labour costs.

An estimate of the price of the new chair is obtained.

4.2.6.- Comparison between old chair and new chair

The study is completed by making a comparison between the old chair and the new designed chair. A table compares the results obtained from the RULA, REBA and OWAS methods, the mechanical behaviour of both chairs, and the results of the ergonomic analyses obtained with Catia. This study shows that improvements have been made to the chair, both at the design and at the ergonomic level.

4.3.- Advantages between the proposed method and the state of the art

The following describes a series of advantages in the use of the proposed flowchart method with respect to the existing method in the state of the art.

- Structured method valid for all types of chairs used in the school environment
- The method evaluates the main methods for the analysis of postural load, RULA, REBA and OWAS, making a complete idea of the various problems (since the methods can not be effective for all parts of the body)
- Identification of ergonomics issues gives information on which aspects to improve by guiding the designer in the implementation of ergonomic solutions / devices
- The design for ergonomics process is coupled to the structural analysis and design part to cost part integrating into the product development process
- The method allows the design of a new chair as many times as necessary until the desired parameters are achieved

5.- Case study: ergonomics redesign of a classroom chair from the campus of Parma

In this chapter we study a classroom chair from the University of Parma. This study includes the measurement and the observation of the postures adopted in the old chair, the 3D design with the Inventor program, an ergonomic analysis with the RULA, REBA and OWAS methods, an analysis of mechanical behaviour also with Inventor and an ergonomic study with Catia.

5.1.- Measurement of the old chair

The study of the old chair starts by taking all the necessary measures of the same for proper sizing. To do this, all measurements of the chair were measured directly with a meter.

5.2.- Observation of the postures adopted in the chair

20 postures are observed with an interval between each observation of 60 seconds. For the following studies with the RULA, REBA and OWAS methods, we will focus on the postures that the user adopted for the most extended time and the one that the user should adopt according to the characteristics of the chair.

The Figure 33 shows both postures.

Figure 33: Postures in which we will focus for this study

5.3.- 3D geometric model with Inventor

In this section all the pieces that are necessary for the 3D modeling of the old chair with the Inventor program are defined, as well as the operations that were carried out for its realization, and the material of each of the pieces.

<u>Seat</u>

The piece called "seat" in Inventor, is performed by a sweeping operation, and then three extrusion operations to shape the edges of the chair and add the two side tabs that are embedded in the side supports. It also joins to the “Support seat left and right” with two screws ISO 7051 - 4,2 x 25.

Together with the backrest it is the most important piece of the saddle set.

Material: plywood

Figure 34: Seat

Backrest

The piece called "backrest" in Inventor, is performed by a sweeping operation, and then two extrusion operations. The first extrusion is to shape the upper edges of the backrest, and the second to add two side tabs to the backrest, which as in the seat, are embedded in the side supports and also they are screwed to the “Support backrest left and right” pieces by means of two screws ISO 7051 - 4,2 x 25.

It is the piece that most influences the ergonomic aspects of the chair.

Material: plywood

Figure 35: Backrest

Support backrest left and right

They are respectively called "Support backrest izq" and "Support backrest dcha" in Inventor, both made by several extrusion operations and a revolution operation to create the screw slot. In these pieces the tabs of the backrest are fitted and screwed through to two screws ISO 7051 - 4,2 x 25, and by means of a bolt the seat supports are joined to them, allowing the rotation of the seat.

In the lower part, the "Support leg" piece is screwed using two ISO 4762 M5 x 50 screws, and the "Leg" piece is screwed using two other ISO 4762 M5 x 50 screws.

Material: steel

Figure 36: Support backrest

<u>Support seat left and right</u>

They are denominated respectively "Left seat support" and "Right seat support" in Inventor, both made by several extrusion operations and a revolution operation to create the screw slot. In these pieces the seat tabs are fitted and screwed through to two screws ISO 7051 - 4,2 x 25, and by means of a bolt they are joined, by the outside of the chair to the supports of the backrest, and on the inside part, to pieces that make the top of both.

Material: steel

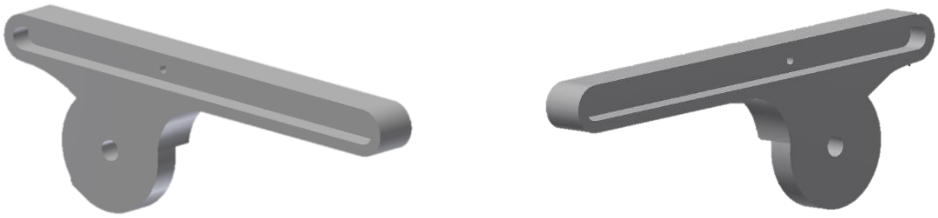


Figure 37: Seat support

Interior support

The piece called "Interior support" in Inventor, is made through two operations. An operation of revolution in which the whole piece is created, and an extrusion operation with which the hole is made through which the bolt passes. The left and right support are the same, so only one piece is created.

Material: steel

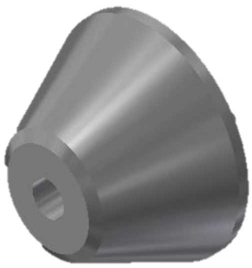


Figure 38: Interior support

Bolt

The piece called "Bolt" in Inventor, is made by an extrusion operation. It is the piece that allows the rotation of the seat and joins the three pieces previously described.

Material: steel

Figure 39: Bolt

Leg

The piece called "Leg" in Inventor, is made by several extrusion, revolution and symmetry operations. It is attached to the piece "Support backrest izq" by means of two screws ISO 4762 M5 x 50, and in between there is a hole for the bar that joins all the chairs in the same row. The lower part is fixed to the floor with two screws ISO 4762 M6 x 20.

It is the piece that supports all the weight of the chair and the force exercised by the user.

Material: steel

Figure 40: Leg

<u>Support leg</u>

The piece called "Support leg" in Inventor, is made by an extrusion operation and by a revolution operation. It is attached to the piece "Support backrest dcha" by means of two screws ISO 4762 M5 x 50, and in between, as in the "Leg" piece, there is a hole for the bar.

Material: steel

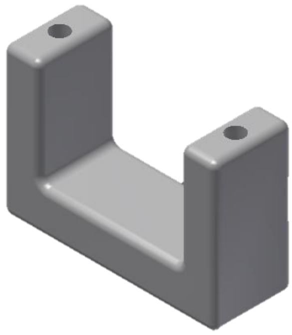


Figure 41: Support leg

<u>Bar</u>

The piece called "Bar" in Inventor, is made by an extrusion operation. It is the piece that makes the union between the chairs that are located in the same row.

Material: steel

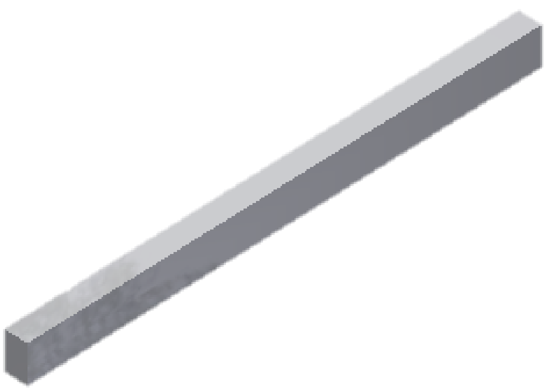


Figure 42: Bar

Chair assembly

Figure 43 shows the set of all the pieces previously described assembled.

Figure 43: Chair assembly

Table

Figure 44 shows the set of the table.

Figure 44: Set of the table

<u>Chair and table set</u>

Figure 46 and Figure 45 show the chair and table set, in this way the position of each of them, and the distance between them is observed.

Figure 46: Chair and table set 1

Figure 45: Chair and table set 2

5.4.- Ergonomic analysis: RULA, REBA, OWAS

In this section, we proceed to evaluate the positions that a user adopts in a lecture room chair at the University of Parma, by means of the three most known methods of evaluating the postural load, which are RULA, REBA and OWAS, in order to know the risk that suffers, in this case a student, for the adoption of inappropriate postures. The user has average anthropometric characteristics compared to Italian university students.

5.4.1.- RULA

This method only evaluates one side of the body, so in this study the left side of the body is evaluated, and the position that the user adopts for the most prolonged time.

The study is based on the following Figure 47, therefore we have to ensure that the measures are in true magnitude.

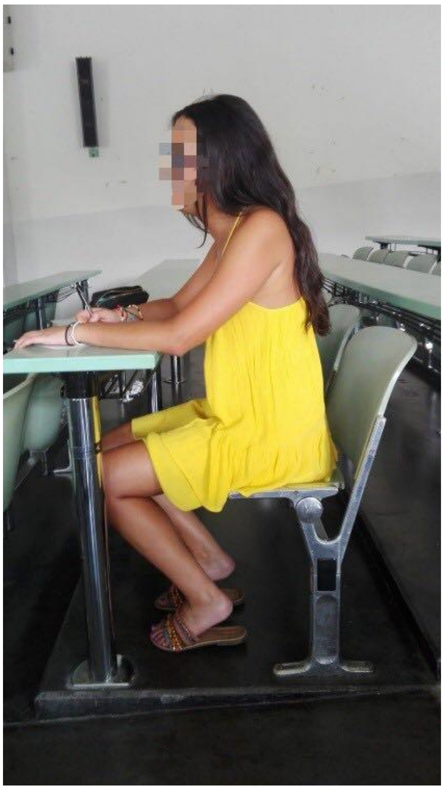


Figure 47: Posture for the most prolonged time

It begins by dividing the body into two groups. Group A, evaluates the position of the upper arm, lower arm and wrist and group B, the position of the neck, trunk and legs.

<u>Group A</u>

Based on the Figure 3 assign a score to each part of the body, as seen in Figure 48.

1) Upper arm position: the arm is between 20 and 45 degrees of flexion →+2.

   The upper arm is abducted → +1

   The arm is supported → -1

2) Lower arm position: the lower arm is between 60 and 100 degrees of flexion →+1

3) Wrist position: the wrist is in neutral position → +1

   The wrist is twisted in mid-range →+1

Figure 48: Posture score group A, RULA

We enter in Table 2 with the values:

Upper arm = 2 Lower arm = 1 Wrist score = 1 Wrist twist = 1	We obtain a provisional score for group A of 2, to which as shown in Figure 5 we add the partial score of the static and repetitive posture = +1, and the partial score in the case where loads are involved = 0.

The final score of group A, will be the sum of the score obtained from Table 2, plus the sum of the partial scores.

Final score for group A = +2 +1 +0 = 3

<u>Group B</u>

For this group we look at Figure 4 and assign a score to each part of the body, as seen in Figure 49.

1) Neck position: the neck is flexed between more than 20 degrees→ +3
   The neck is twisted → +1
2) Trunk position: the trunk is flexed between 0 and 20 degrees → +2
3) Legs positions: The worker is sitting with legs and feet well supported → +1

Figure 49: Posture score group B, RULA

We enter in Table 3 with the values:

Neck posture score = 4
Trunk posture score = 2
Legs = 1

We obtain a provisional score for group B of 5, to which as shown in Figure 6 we add the partial score of the static and repetitive posture = +1, and the partial score in the case where loads are involved = 0.

The final score of group B, will be the sum of the score obtained from Table 3, plus the sum of the partial scores.

Final score for group B = +5 +1 +0 = 6.

With the final score for group A = 3 and the final score for group B = 6 we enter in Table 4 and obtained the final score for the RULA method of 5, which means that more investigations are needed and changes must be done soon.

5.4.2.- REBA

REBA evaluates individual postures and not sets or sequences of postures. You have to choose between evaluating the posture by their duration, by their frequency or because they have greater deviation from the neutral position. In this case, two positions will be evaluated. The first is the posture that the user adopts for the most prolonged time (the same evaluated for the RULA method), and the second one, the posture that the user should adopt according to the characteristics of the chair. In both cases is the left side in which the study is focused.

This method divides the body in two groups. Group A that includes the trunk, neck and legs, and the group B, which includes the upper arms, lower arms and wrists.

First the posture that the user adopts for the most prolonged time is studied, Figure 47.

<u>Group A</u>

For this group we look at Figure 8 and assign a score to each part of the body, as seen in Figure 50.

1) Neck position: the neck is flexed between more than 20 degrees→ +2
   The neck is twisted → +1
2) Trunk position: the trunk is flexed between 0 and 20 degrees → +2
3) Legs positions: The worker is sitting with legs and feet well supported → +1

We enter in Table 5 with the values:

Neck posture score = 3 Trunk posture score = 2 Legs = 1	We obtain a provisional score for group A of 4, to which we add the partial of loads. In this case there are no loads, so the score for group A is = 4 + 0 = 4

Figure 50: Posture score group A, REBA

<u>Group B</u>

Based on the Figure 9 assign a score to each part of the body, as seen in Figure 51.

1) Upper arm position: the arm is between 20 and 45 degrees of flexion →+2.

   The upper arm is abducted → +1

   The arm is supported → -1

2) Lower arm position: the lower arm is between 60 and 100 degrees of flexion →+1

3) Wrist position: the wrist is in neutral position → +1

Figure 51: Posture score group B, REBA

We enter in Table 6 with the values:

Upper arm = 2
Lower arm = 1
Wrist score = 1

We obtain a provisional score for group B of 1, to which we add the "Coupling" score, in this case +0. The final score for group B is = 1 + 0 = 1

With the final score of group A = 4 and group B = 1, we enter in Table 7 and obtain a score of 3, to which an activity score is added, in this case some body parts are held for longer than 1 minute, so to the score obtained before, we sum +1 (the activity score).

The final score for the REBA method is 4, which means that there is a medium level of risk, a deeper investigation must be done and changes must be implemented in the chair.

The second posture studied, is the one that the user should adopt according to the characteristics of the chair, Figure 52.

Figure 52: Second posture for REBA

The same steps are followed as in the previous case. It begins by dividing the body into two groups.

Group A

For this group we look at Figure 8 and assign a score to each part of the body as seen in Figure 53.

1) Neck position: the neck is flexed between 10 and 20 degrees→ +1

   The neck is twisted → +1

2) Trunk position: the trunk is in extension → +2
3) Legs positions: The worker is sitting with legs and feet well supported → +1

Figure 53: Posture score group A, REBA 2

We enter in Table 5 with the values:

Neck posture score = 2

Trunk posture score = 2

Legs = 1

We obtain a provisional score for group A of 3, to which we add the partial of loads. In this case there are no loads, so the score for group A is = 3 + 0 = 3

Group B

Based on the Figure 9 assign a score to each part of the body as seen in Figure 54.

1) Upper arm position: the arm is between 45 and 90 degrees of flexion → +3

The upper arm is abducted → +1

The arm is supported → -1

2) Lower arm position: the lower arm is between 60 and 100 degrees of flexion →+1
3) Wrist position: the wrist is in neutral position → +1

Figure 54: Posture score group B, REBA 2

We enter in Table 6 with the values:

Upper arm = 3
Lower arm = 1
Wrist score = 1

We obtain a provisional score for group B of 3, to which we add the "Coupling" score, in this case +0. The final score for group B is = 3 + 0 = 3

With the final score of group A = 3 and group B = 3, we enter in Table 7 and obtain a score of 3, to which an activity score is added, in this case some body parts are held for longer than 1 minute, so to the score obtained before, we sum +1 (the activity score).

The final score for the REBA method is 4, which means that there is a medium level of risk, a deeper investigation must be done and changes must be implemented in the chair.

5.4.3.- OWAS

Unlike the RULA and REBA methods, OWAS is characterized by its ability to assess all the positions adopted during the performance of the task jointly. The postures are collected at regular intervals of time, between 30 and 60 seconds. In this study, 20 postures with an interval between each of 40 seconds were evaluated.

It begins by evaluating the Figure 47.

Based on the Figure 11 assign a score to each part of the body.

Back posture: straight → 1
Arms posture: both below shoulder → 1
Legs: sitting → 1

With these scores, we enter in Table 8, and get the class that reflects static load risk degree, class 1.

According to the OWAS method the user adopts a normal posture, so no intervention is required.

Another posture evaluated was the Figure 52.

As in the previous example, the study is based on the Figure 11 and then a score to each part of the body is assigned.

Back posture: straight → 1
Arms posture: both below shoulder → 1
Legs: sitting → 1

With these scores, we enter in Table 8, and get the class that reflects static load risk degree, class 1.

The same result is obtained as in the previous posture, that is, according to the OWAS method the user adopts a normal posture, so no intervention is required.

Next posture evaluated is shown in Figure 55.

Figure 55: Example posture OWAS

Based on the Figure 11 assign a score to each part of the body.

Back posture: straight → 2

Arms posture: both below shoulder → 1

Legs: sitting → 1

With these scores, we enter in Table 8, and get the class that reflects static load risk degree, class 2.

Class 2 means that the posture is slightly harmful and a corrective action should be taken during next regular review of working methods.

In the rest of the postures evaluated, class 1 or class 2 is obtained as result, since only the score of the back varies.

As it can be verified, this method is not suitable for our study, since it does not divide the arms in upper and lower arms and does not include assessments of neck and elbows/wrists. It is considered to be a very simple study in our case, in relation to the RULA and REBA methods.

Table 15 summarizes the chosen positions and the results obtained depending on the method used.

Table 15: Summary of the RULA, REBA and OWAS methods studied

	Posture studied	Score	Meaning of the score
RULA	The one that the user adopts for the most prolonged time	5	More investigations are needed and changes must be done soon.
REBA	The posture that the user adopts for the most prolonged time and the one that the user should adopt according to the characteristics of the chair	4	There is a medium level of risk, a deeper investigation must be done and changes must be implemented in the chair.
OWAS	20 different postures	1 or 2	The user adopts a normal posture, so no intervention is required or the posture is slightly harmful and a corrective action should be taken

These scores require a new approach oriented to the redesign of the ergonomic of the old chair.

5.5.- Analysis of mechanical behaviour with Inventor

With Inventor, a mechanical analysis of the chair modeled is performed, applying forces in a position and with certain loads according to the UNI-EN 1729-2: 2006 norm, and the response of the chair to these loads is analyzed, in order to check its resistance.

According to the norm the chair must perform a series of tests to ensure the correct design of it. These tests are forward and sideways stability, rewards stability and seat and back static load of the chair.

5.5.1.- Fixation of surfaces

The first step is to fix the necessary surfaces to avoid the displacement and deformation in them. The lower surface of the leg and the external face of the bar are fixed as can be seen in Figure 56.

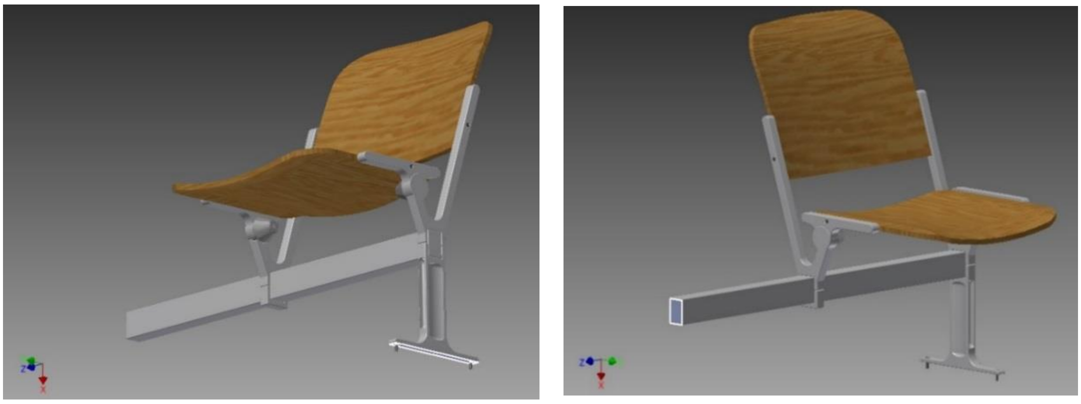


Figure 56: Fixation of surfaces

5.5.2.- Tests

According to the UNI-EN 1729-2: 2006 norm, four tests are made: forward, sideways and rewards stability, and seat and back static load of the chair.

a. Forward stability of the chair

It starts by evaluating the chair with a load located in the position shown in Figure 16. The Table 16 shows the position of the force and the load applied for this case, which is subsequently represented in Figure 57.

Table 16: Forces for the test forward stability of the chair

Position of the force	Applied load [N]
Vertical force in the middle front of the seat	600
Horizontal force in the middle front of the seat	20

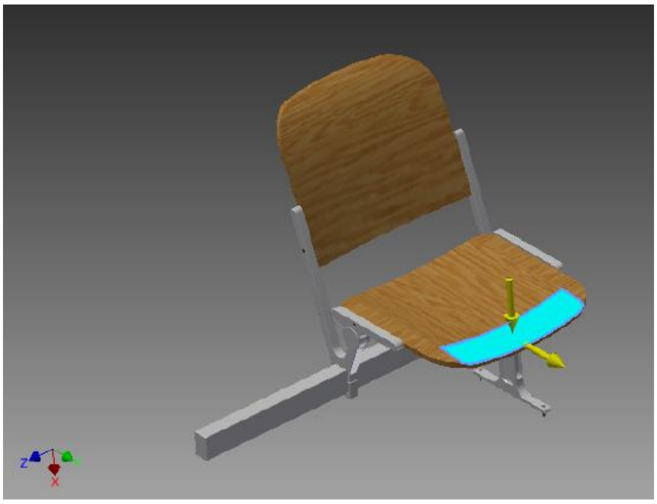


Figure 57: Positions of the loads for the forward stability

b. Sideways stability of the chair

A force is applied in the position that marks the norm as shown in the Figure 17. As in the previous test, the Table 17 shows the position of the force and the load applied for this case, as the Figure 58 shows.

Table 17: Forces for sideways stability of the chair test

Position of the force	Applied load [N]
Vertical force in a side of the seat	600
Horizontal force in a side of the seat	20

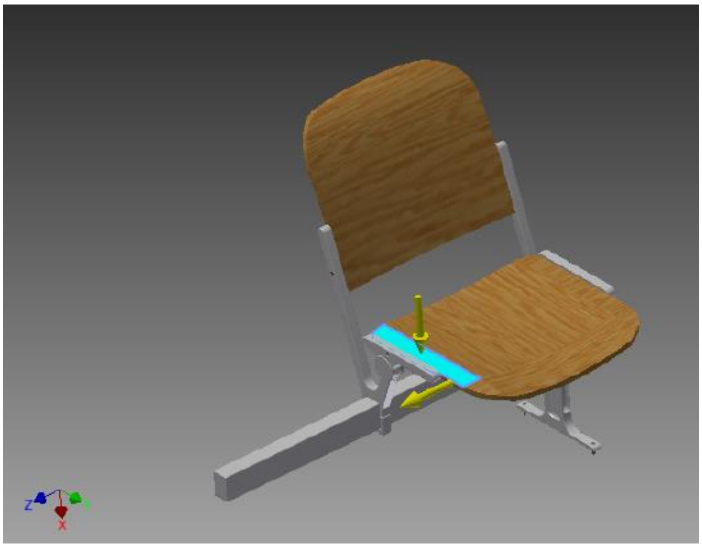


Figure 58: Positions of the loads for the sideways stability

c. Rewards stability of the chair

According to the Figure 18, some forces are applied to the seat and the backrest as Table 18 shows. These forces are represented in Figure 59.

Table 18: Forces for rewards stability of the chair test

Position of the force	Applied load [N]
Vertical force in the middle of the seat	600
Horizontal force in the middle of the back of the backrest	180

Figure 59: Positions of the loads for the rewards stability

d. Seat and back static load of the chair

As shown in the Figure 19, a force in the backrest and in the seat are applied in the determined position as Table 19 shows. These forces are represented in Figure 60.

Table 19: Forces for seat and back static load of the chair test

Position of the force	Applied load [N]
Vertical force in the middle of the seat	2000
Horizontal force in the middle of the front of the backrest	700

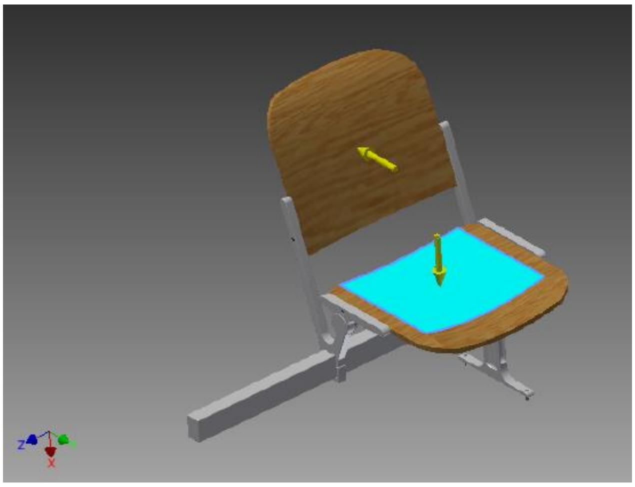


Figure 60: Positions of the loads for the seat and back static load test

5.5.3.- Results of the study

To verify that the chair responds correctly to the forces applied in it, the following parameters are analyzed:

- Von Mises tensions
- Deformations
- Displacement

a. Von Mises tensions

A Von Mises analysis is performed in each test, in which the maximum effort to which each piece is subjected can be seen. The Table 20 contains the summary of the maximum and minimum efforts collected for each test.

Table 20: Von Mises tensions

	Von Mises tensions [MPa]	
	Minimum	**Maximum**
Forward stability	0	206,0
Sideways stability	0	63,4
Rewards stability	0	63,5
Seat and back static load	0	257,0

The maximum tension of Von Mises is 257 MPa and is given in the test of “Seat and back static load”, since it is the test in which a bigger force is applied, 2000N is applied to the seat.

The following figures show the Von Mises tension graphs for the four tests.

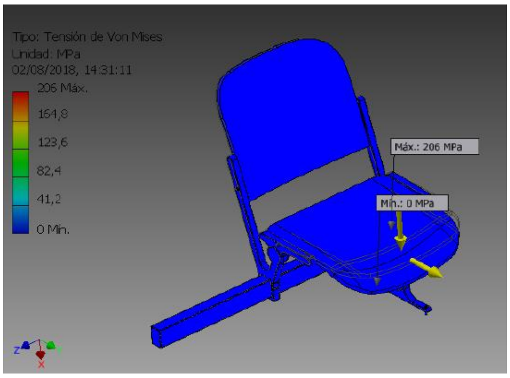


Figure 61: Graphic of Von Mises first test

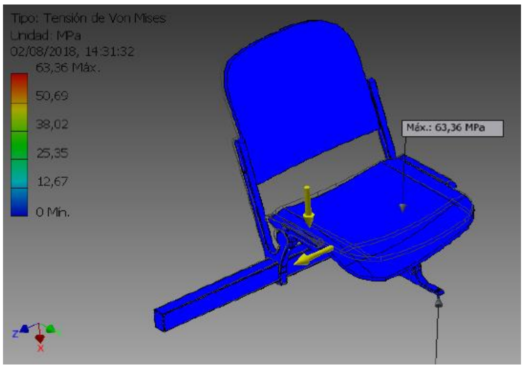


Figure 62: Graphic of Von Mises second test

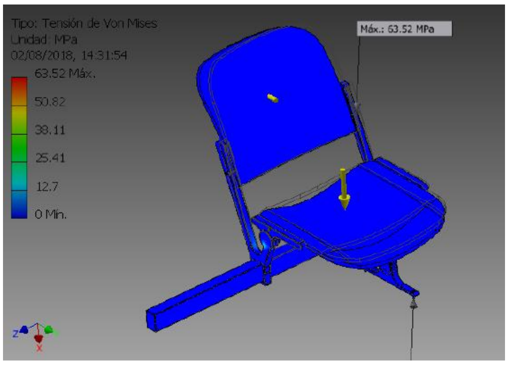


Figure 63: Graphic of Von Mises third test

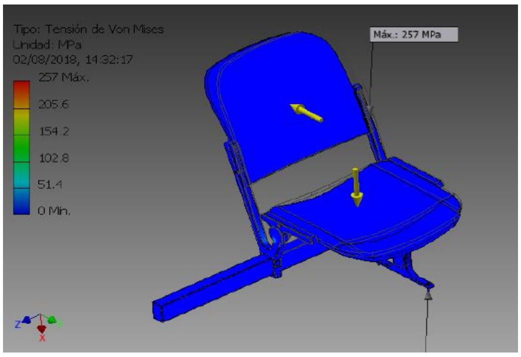


Figure 64: Graphic of Von Mises fourth test

In the first test "forward stability of the chair", Figure 61 shows where the maximum Von Mises' tension is applied. This tension is located in the center of the seat, but also the seat supports are subject to a Von Mises tension of approximately 41.2 MPa, as can be seen in the Figure 65.

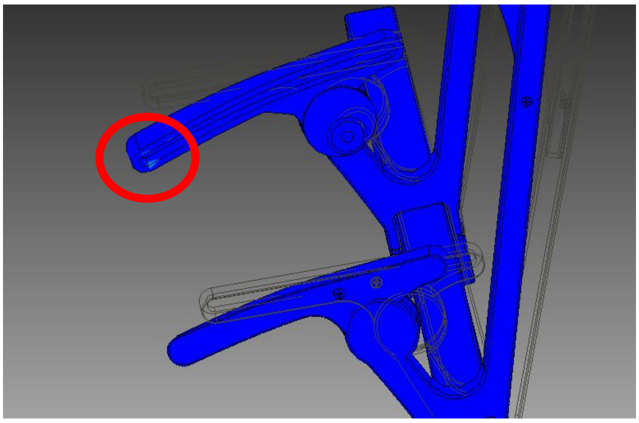


Figure 65: Von Mises tension in the "forward stability of the chair" test

In the second test "sideways stability of the chair", the Von Mises maximum tension is shown in Figure 62, also in the center of the seat. As in the first test, the seat supports are subject to a Von Mises tension (light blue area) of approximately 12,67 MPa as shown in Figure 66.

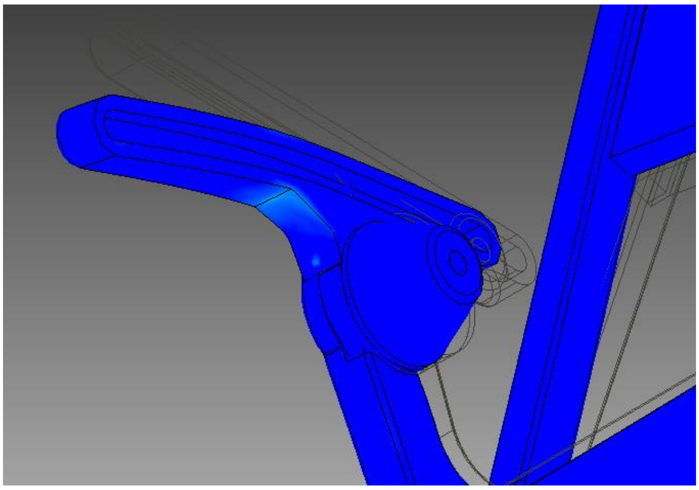


Figure 66: Von Mises tension in the "sideways stability of the chair" test

The Figure 63 shows where is applied the maximum Von Mises tension for the third test, "rewards stability of the chair". This tension is applied in the ends of the lower part of the backrest. The Figure 67 shows the place where the bolt and the back supports are subjected to a Von Mises voltage of approximately 12.7MPa.

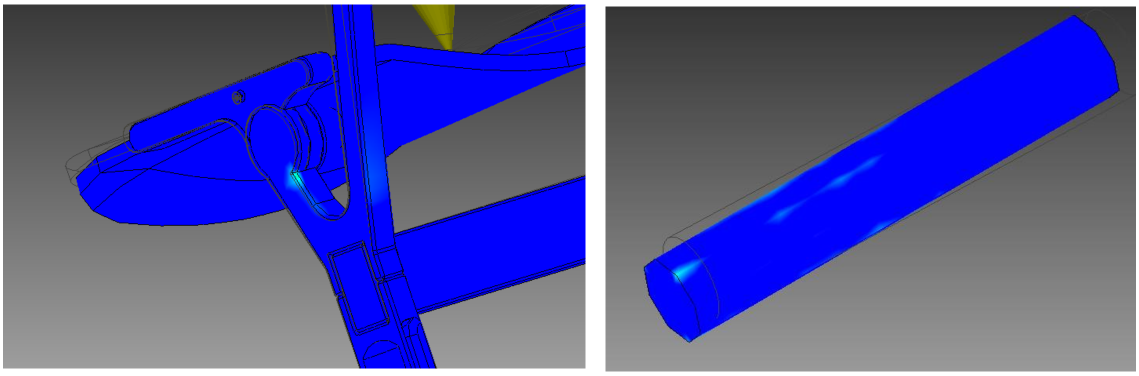


Figure 67: Von Mises tension in the "rewards stability of the chair" test

In the fourth test, "seat and back static load of the chair", the Figure 64 shows where the maximum Von Mises' tension is applied. As in the previous test, it is applied in the ends of the lower part of the backrest. In the Figure 68, is shown a Von Mises' tension applied in the backrest support of approximately 51,4 MPa.

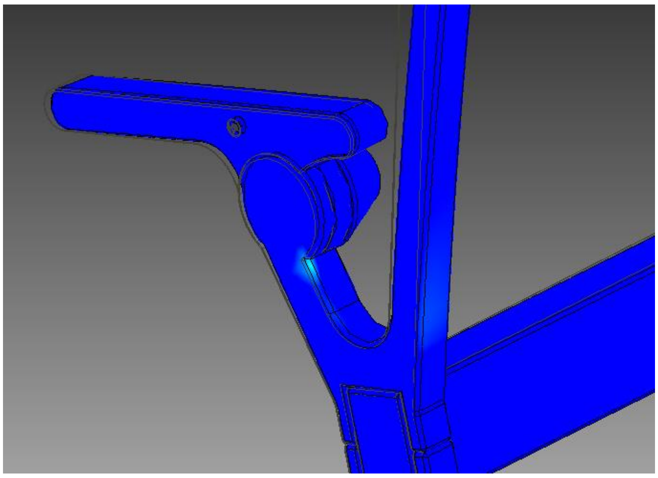


Figure 68: Von Mises tension in the "seat and back static load of the chair" test

b. Deformations

In terms of deformations, the Table 21 shows the maximum deformations of each piece according to the test that has been applied.

Table 21: Deformations

	Deformation	
	Minimum	**Maximum**
Forward stability	0	0,002404
Sideways stability	0	4,556e-004
Rewards stability	0	8,501e-004
Seat and back static load	0	0,004122

The maximum deformation is 0,0041222, which also corresponds to the "Seat and back static load" test. The following figures show the graphics of deformation for the four tests.

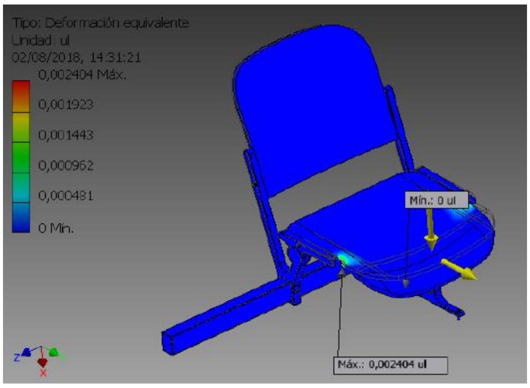


Figure 69: Graphic of deformation first test

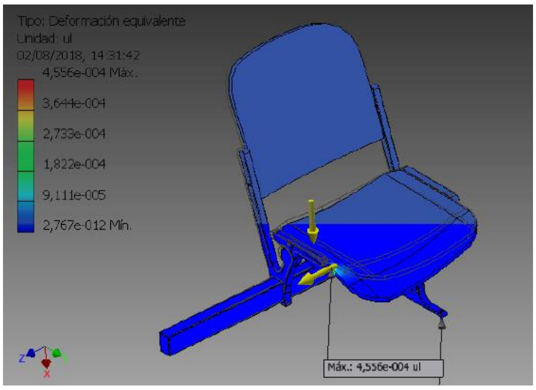


Figure 70: Graphic of deformation second test

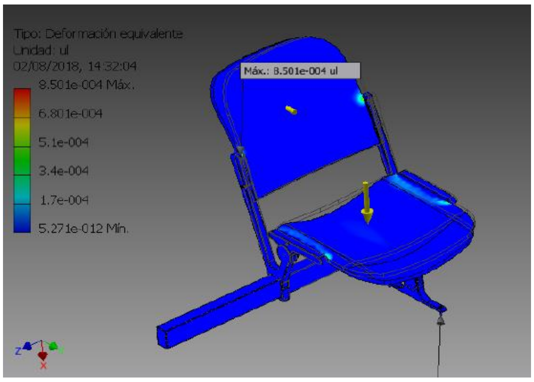


Figure 71: Graphic of deformation third test

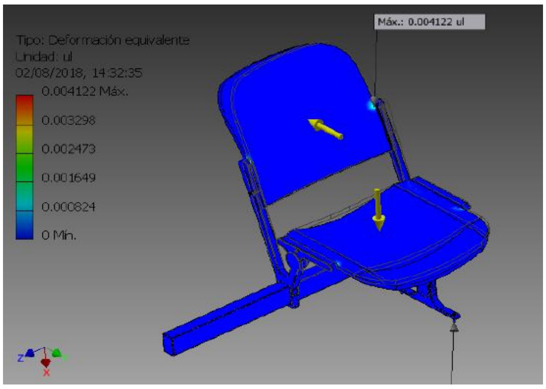


Figure 72: Graphic of deformation fourth test

In the first test "forward stability of the chair", Figure 69 shows where the maximum deformation is applied, which is given on the sides of the seat. It is seen more clearly in the Figure 73, where the maximum deformation corresponds to the red areas.

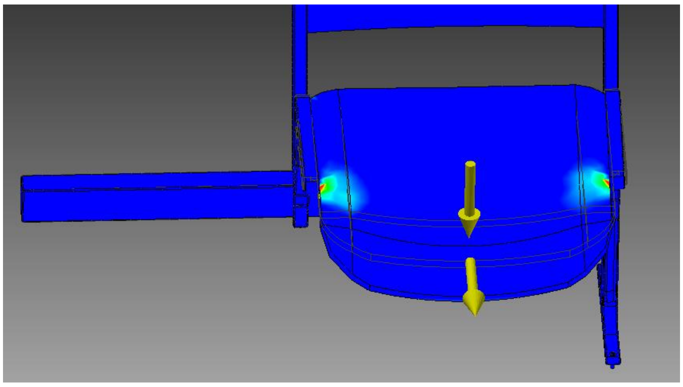


Figure 73: Deformation in the "forward stability of the chair" test

In the second test "sideways stability of the chair", the maximum deformation is given on the right side of the seat, as shows the Figure 74.

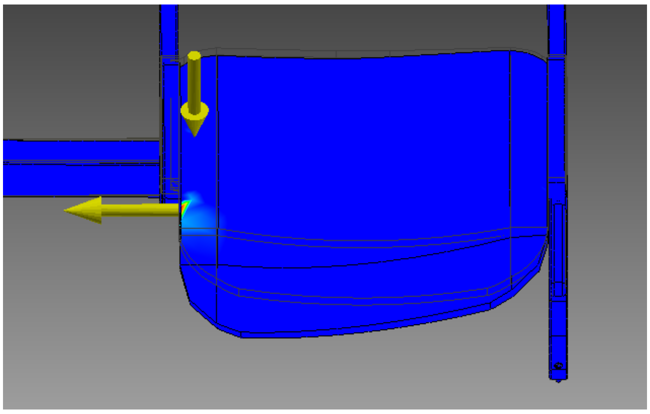


Figure 74: Deformation in the "sideways stability of the chair" test

The chair in the third test, "rewards stability of the chair", suffers the maximum deformation on the sides of the backrest. It also suffers an important deformation on the sides of the seat (light blue area), as shown Figure 75.

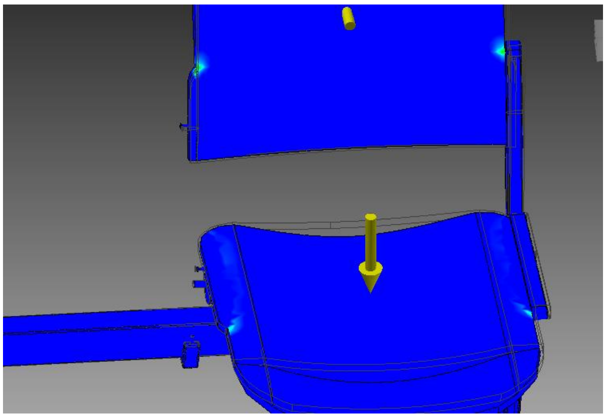


Figure 75: Deformation in the "rewards stability of the chair" test

As in the previous test, in the fourth test, "seat and back static load of the chair", the maximum deformation is given on the sides of the backrest, and the sides of the seat, also suffers an important deformation, Figure 76.

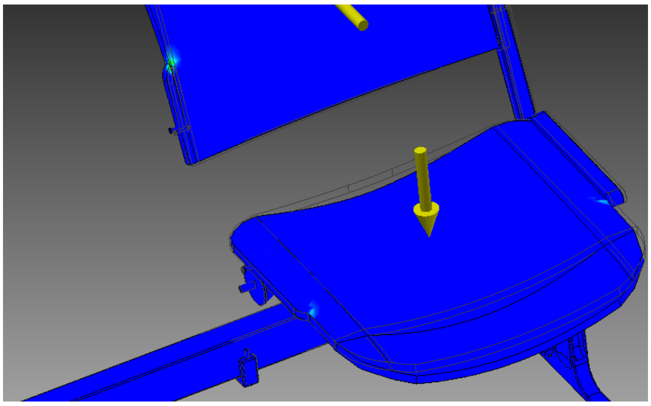


Figure 76: Deformation in the "seat and back static load of the chair" test

c. Displacement

As in the other parameters analyzed, the Table 22 includes a summary of the displacements suffered by the pieces depending on the test applied.

Table 22: Displacement

	Displacement [mm]	
	Minimum	**Maximum**
Forward stability	0	2,8
Sideways stability	0	0,4
Rewards stability	0	1,1
Seat and back static load	0	4,6

The maximum displacement is 4,6 mm that it also corresponds to the "Seat and back static load" test.

The Figure 77 shows the graphics of displacement for the four tests. The red areas indicate where the maximum displacement is given for each test. However, the displacement observed in this figure is an exaggerated displacement to facilitate the user's understanding of the images. In reality this displacement is not almost appreciated since it is 4,6 mm.

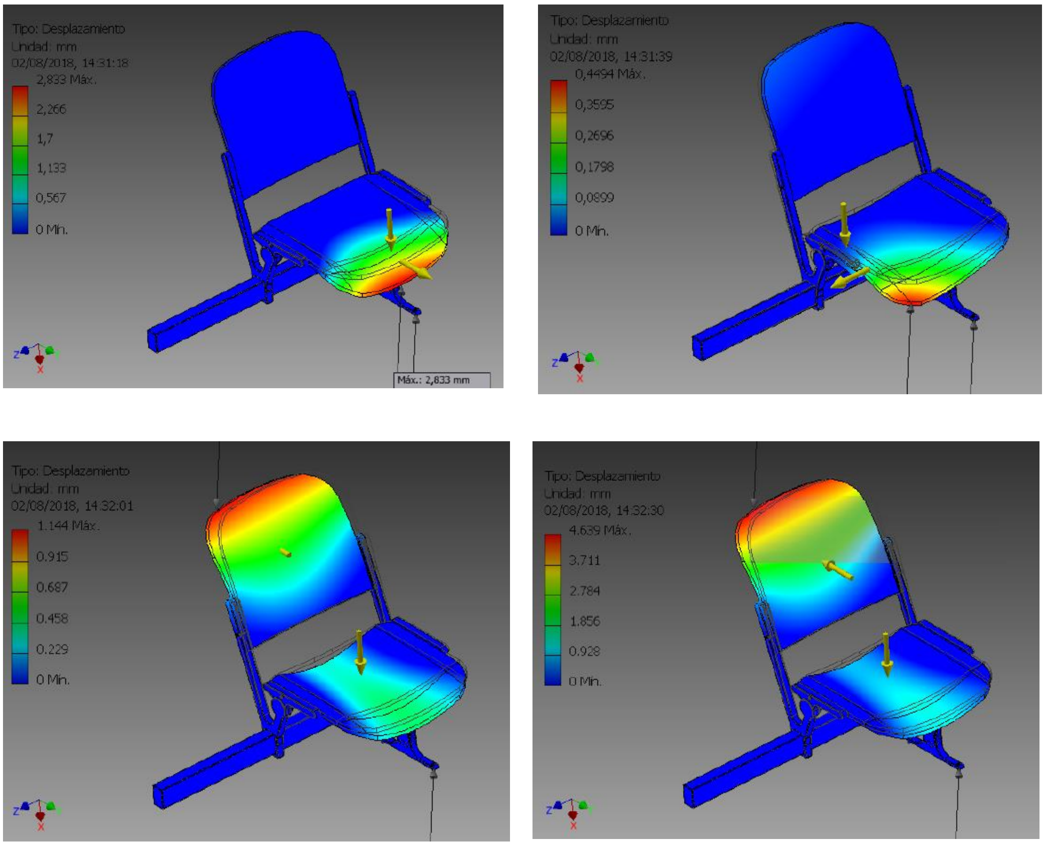


Figure 77: Graphics of displacement

5.6.- Ergonomic study with Catia

An ergonomic study is carried out with the Ergonomic Design and Analysis module of the program Catia V5.

5.6.1.- Creation of the manikin

It begins by designing a manikin through the sub module Human Builder. It defines the gender, percentile and nationality of the manikin, Figure 78. The chosen manikin has the following characteristics:

- Gender: Man
- Percentile: 50
- Nationality: French (Catia does not have the option to choose Italian nationality)

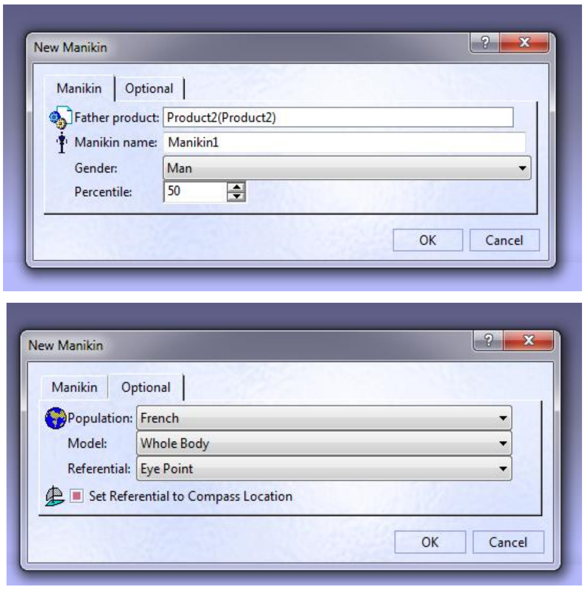


Figure 78: Characteristics of the manikin

Once the characteristics are chosen, the manikin is created, Figure 79.

Figure 79: Manikin Catia

Afterwards, the chair designed in Inventor is inserted and the manikin is manipulated using the option Standard pose, Posture editor and with the help of the compass until it adopts the desired position in the chair, Figure 80.

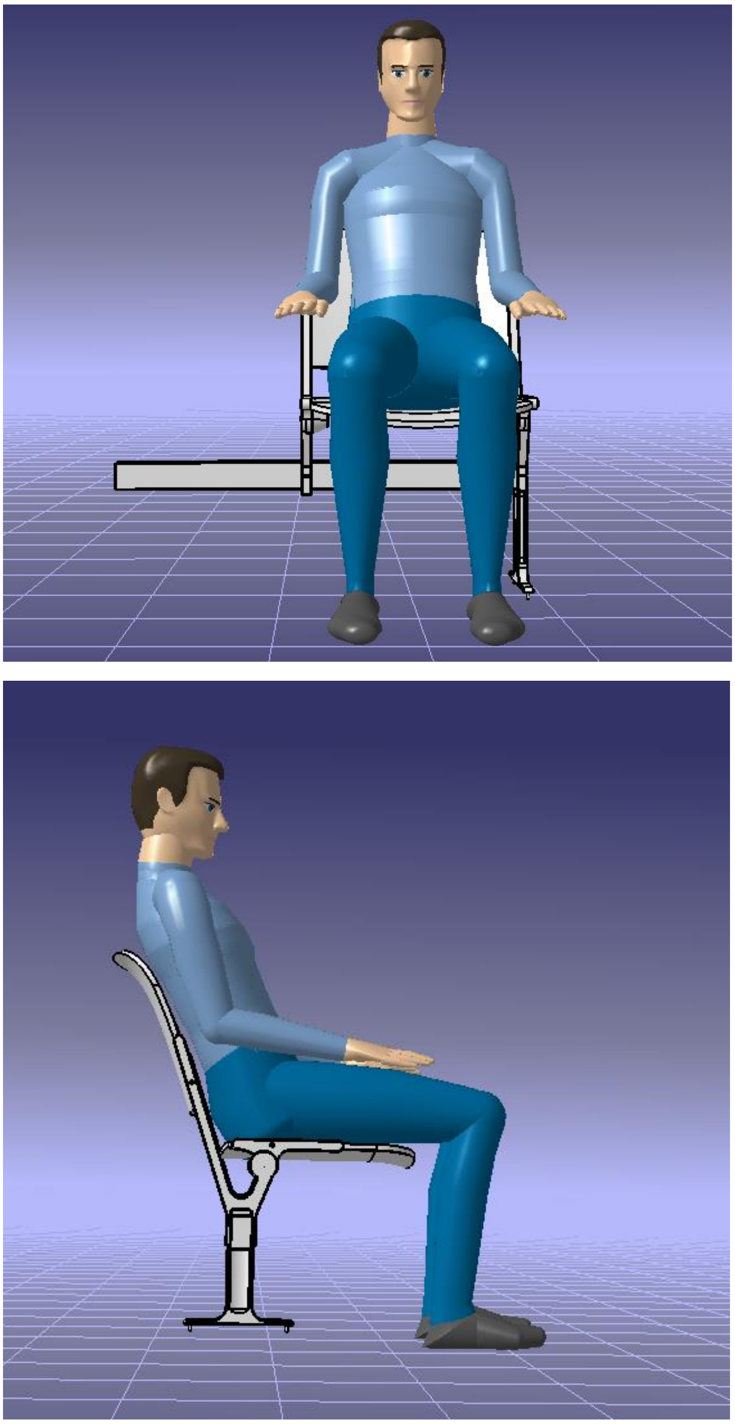


Figure 80: Chair and manikin in Catia

5.6.2.- RULA analysis with Catia

With the Human Posture Analysis, the posture adopted by the manikin in the chair is analyzed. For this, the RULA method is used. First, a series of parameters are chosen, such as:

- The side to be evaluated: in this case left side.
- Type of posture: repeated
- Arms supported

Once the parameters have been chosen, the program automatically evaluates the posture and, as an output, the score of the RULA method is obtained. In this case, the final score of the RULA method is 5, which means that a further investigation is needed and the chair should be change soon.

With this analysis, we obtain the same result as that obtained through the RULA observational method, in which we also obtained a final score of 5, as can be seen in the section 5.4.1.-.

In the Figure 81, the score obtained by each part of the body, the final score of group A and B, as well as the final score of the RULA method are detailed.

Each part of the body is assigned a green, yellow or red color depending on the position adopted by each one, being green the position in which there is no risk when adopting it, and red the position with more risk and which it must be changed soon.

As seen in the Figure 81 the neck is the part of the body with the greatest risk of developing lesions in that area because the angle between the trunk and it, is quite large. This causes the final score of group B to rise, and as a result the final score for this method is higher too.

On the other hand, the score "muscle" is in red because it is a static and repetitive posture.

Finally, the score "Neck, Trunk and Leg" is the sum of the score B plus the score "muscle".

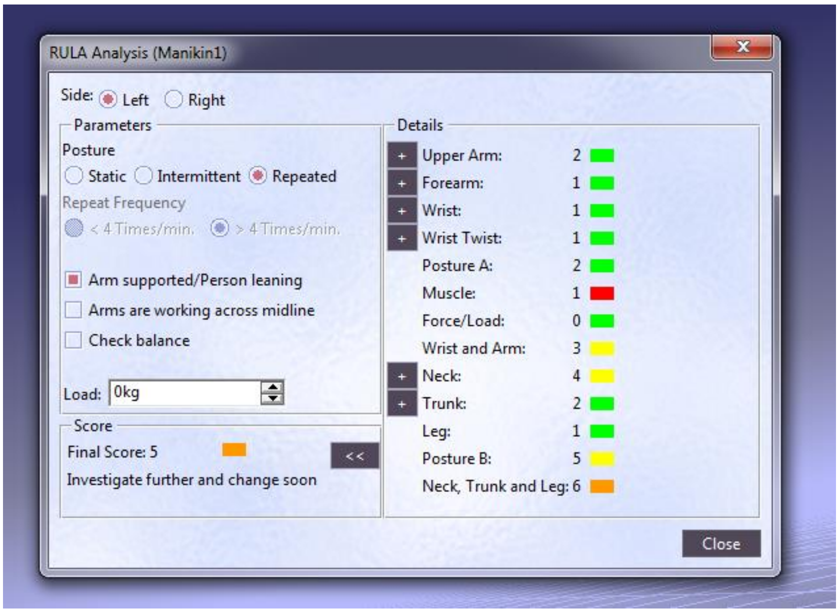


Figure 81: RULA analysis with Catia

5.7.- Identification of critical parameters

We will design a chair adapted to the students of the University of Parma to improve the comfort and social welfare of the students. It is essential to improve it and adapt it to the positions that the students adopt when writing, as well as taking into account the distance that separates the table from the chair and its height with respect to the floor, considering the long time they have to stay in the classrooms.

On the other hand, the chair should favour the mobility of the student, that is, make it easier for students to adopt different positions throughout the day of classes, and consider a free and safe access and exit from the study position.

It should be noted, that there is no unique and ideal position that completely avoids musculoskeletal symptoms and disorders, otherwise there are more favourable positions that allow reducing them.

For the design of the redesigned chair of the University of Parma we must adopt the following parameters, to make the students take correct postures.

1. The soles of the feet must be resting on the ground. Usually, they support more or less 20% of the weight of the body in a normal sitting position. This lack of support will produce discomfort and muscle fatigue.

2. The chair must favour the change of leg position throughout the class day. The low seats reduce the angle between legs and trunks and produce instability in it, while high seats, force students to move to the front of the seat losing support from the back in the backrest. No obstacle limiting the movement of the legs should be incorporated under the seat, Figure 82.

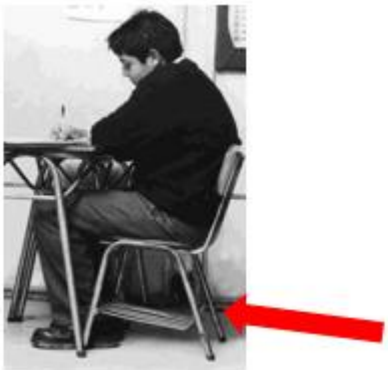


Figure 82: Obstacle that prevents the movement of the legs

3. The area of the buttocks and thighs should favour a stable and functional posture of the trunk. For this, the width of the seat should support the entire buttock region, minimum 400 mm. As for the depth of the seat, the thighs should not be subjected to pressure in the popliteal region (area at the bottom and back of the thigh), as this pressure could cause discomfort and tingling in the area, minimum 460 ±25 mm, Figure 83.

Figure 83: Seat that does not compress popliteal region

4. The back should have support at the level of the lumbar spine and the posture should favour the perception of visual information. The angle between the thigh and the trunk can range between 95 to 100 degrees to ensure that the trunk and head are located in such a way as to facilitate the student's perception of visual information. Otherwise, if the angle is less than 95 degrees, the back does not rest on the backrest, accelerating the fatigue of the musculature that supports the weight of the trunk.
5. It is necessary a gap between the backrest and the seat to adequately support the back and accommodate the curvature of the gluteal region.
6. In relation to the position of the arms, the arm should be next to the trunk, and the elbow should be supported on the table without having to raise the shoulders, so that the muscles around the neck do not pull the cervical spine and the head too strong. Although we consider acceptable situations in which the separation of the arm with respect to the trunk does not exceed 30 to 40 degrees, Figure 84.

Figure 84: Angle between the arm and the trunk

7. The front part of the seat should be tilted down so that it does not press the back of the knees or hinder the circulation of the legs and the seat should be wide and deep enough so that approximately 2/3 of the thigh is supported, Figure 85.

Figure 85: Front part of the seat
tilted down

8. It is important that the chair has an easy entry and exit to the workplace for safety reasons.
9. The edges / welding should be rounded, without sharp edges that can be stuck in the user and there should be no screws or projections that can dig into the user or get caught in their clothes.

Once the recommendations are established, we must consider the anthropometric dimensions of the user population so that the design of our chair adapts as best as possible to all the students, although it is a difficult problem to solve considering the natural postures and movements that the students will perform because of the daily activity in the classroom (write, raise their heads, lean back ...) and assume the wide variety of students with a multitude of body dimensions.

In this case, the body size of the students of the University of Parma, will be the centre of study for the design of the ergonomic chair.

These anthropometric values are usually expressed in percentiles [14]. We will use in our case the percentile 50.

In Italy, the data to be taken into account would be 177,8 cm for men and 164,6 cm for women.

6.- Ergonomic redesign of the University of Parma chair

Taking as reference the old chair, a new chair is redesigned with the appropriate improvements based on the results obtained through the RULA, REBA and OWAS methods, on the ergonomic analysis with Catia and on the critical parameters. Therefore, a more ergonomic chair is obtained in which the users can adopt a better posture.

The improvements made in the pieces of the chair are described below.

Seat

The main improvement in the new chair will be based on the numerous studies carried out by A.C. Mandal at the Finsen Institute (Copenhagen, Denmark), in which it leaves aside the idea that the angle between the trunk and the thighs must be 90 degrees to be considered a good posture, since through medical studies has been proven negative consequences on the lumbar and cervical spine.

The chair design that involves the user adopting a posture whose angle between trunk and thighs is 90 degrees, is a very common mistake, since no student can maintain the posture for more than a few minutes, so it is common to move forward on the seat to reduce the right angle in the hips.

The studies carried out by A.C. Mandal, allowed to establish that a healthy posture is one whose angle between the trunk and the thighs is greater than 90 degrees. This increase in the angle makes the body tend to slip from the seat but can be avoided by the appropriate design of the chair.

Numerous chairs have already adopted this new design with which an angle between the thighs and trunk greater than 90 degrees is achieved, promoting an upright posture, avoiding tension in the neck and shoulders and reducing the pressure on the vertebral discs. Example of these chairs are shown in Figure 86.

Figure 86: Example of chairs with thigh-trunk angle greater than 90 degrees

The width and depth of the seat will remain the same as that of the old chair, they are respectively, 445 mm and 435 mm, since they are acceptable dimensions according to the standard UNE-EN 1729-1:2015, as can be seen in the Table 10.

The front part of the seat will remain tilted down so that it does not press the back of the knees and also the concavity in the seat.

On the other hand, it is very important to choose the correct distance between the chair and the table, so the current distance is reduced which prevents students from moving in front of the seat to write and read better, since in a generic way, the ideal reading distance between the eyes and the book is 35-40 cm.

<u>Backrest</u>

The backrest will be designed with a slight prominence that will support the lower back, since it is one of the areas where more attention should be paid to avoid injuries and bad postures. This lumbar support favours the erect position of the user.

In the Figure 87, an example of the curvature that will be made on the back of the new chair to improve the support of the lower back is shown.

Figure 87: Example backrest with lumbar support

There will also be a gap between the backrest and the seat that will accommodate the curve of the gluteal region.

The width and height of the backrest will be respectively 447 mm and 367 mm, acceptable dimensions according to the UNE-EN 1729-1: 2015 standard, as can be seen in the Table 10.

<u>Table</u>

It is very important to design the convenient height of the desk. This height is usually between 67 to 75 cm, commonly manufactured with a height of 70 cm, so the new design of the table will reduce the height of it to reach 70 cm in height, in order to favour correct postures to the majority of users.

Although the object of this study is not the modification of the dimensions of the table, it is considered that the width of it is too small to work comfortably in it, so it is extended to 40 cm to achieve greater comfort, but same time that it does not occupy too much space.

<u>Material</u>

The material of the seat and backrest, in addition to being resistant to use, must have non-slip properties, avoiding extremely smooth materials, so the material must have a texture with a roughness that increases the friction generated by the seat and backrest.

The new seat and backrest will be made of polypropylene. It is an extremely hard plastic whose two main advantages are: its resistance to the passage of time (shock, contact with chemicals, heat or cold ...), as well as its ease of handling, processing and reuse by the manufacturer.

On the other hand, it is ecological material. The ductility or malleability of polypropylene makes it one of the most sustainable ecological materials that we can incorporate into the classroom.

Polypropylene allows us to choose the final colour of our product since there is a wide range of colours in the market. The new chair will be light blue, as it is a neutral tone that produces a calm and relaxed atmosphere.

As for the rest of the structure, it will be manufactured in steel due to its great mechanical resistance and its extended use in the industry that will reduce the final price of the chair, facilitate manufacturing and maintenance, increasing the useful life of the assembly.

<u>General features</u>

All edges of the chair will be rounded with a minimum radius of 2 mm, and in the pieces will be created holes where the heads of the screws can be housed, to prevent the user from getting nailed by them or getting caught in the clothes.

6.1.- Redesign in 3D

A 3D model of the redesigned chair is done with the Inventor program, with the previously described characteristics, as well as the explanation of the operations that were carried out for the realization of each piece, and the material used in each case.

<u>Seat ergonomic</u>

The piece called "seat erg" in Inventor, is performed by a sweeping operation, five extrusion operations to shape the edges of the chair and add the two side tabs that are embedded in the side supports, a symmetry operation and an operation called "hole" with which the holes for the screws are made. The main difference that is seen in the seat, is the inclination of the same in the back of 170 degrees respect to the horizontal. It also joins to the "Support seat left and right" with two screws ISO 7046-2 H M4X30. Material: polypropylene

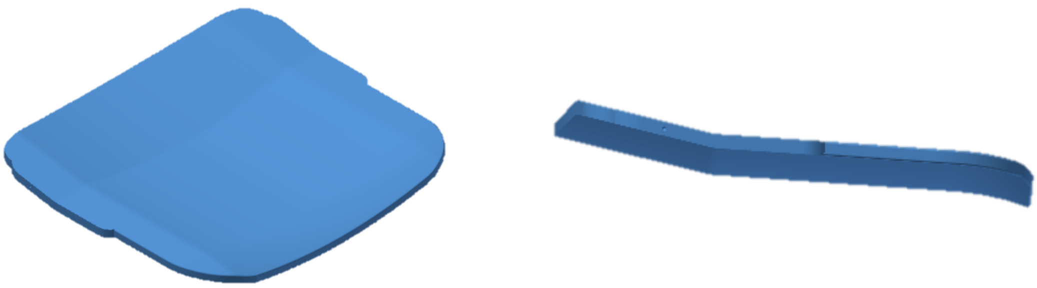


Figure 88: Seat ergonomic

Backrest ergonomic

The piece called "backrest erg" in Inventor, is performed by a sweeping operation, two extrusion operations, two splicing operations and an operation called "hole" with which the holes for the screws are made. With the two sweeping operations, the basic shape of the backrest is made, and the prominence that will support the lower back is created. Later with the extrusion operations, two side tabs to the backrest are created which will be attached to the "Support backrest left and right erg" pieces by means of two ISO 7046-2 H M4X30 screws. Finally, the splicing operations, round all the edges so that no sharp edges remain.

Material: polypropylene

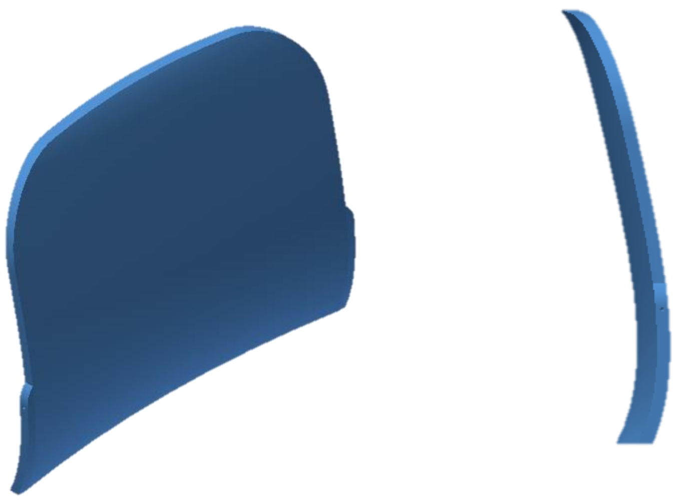


Figure 89: Backrest ergonomic

Support backrest left and right ergonomic

They are respectively called "Support backrest left erg" and "Support backrest right" in Inventor, both made by seven extrusion operations, two sweep operations, two splice operations, and one operation called "hole". With the extrusion and sweeping operations, the basic shape of the pieces and the holes in which the tabs of the backrest are fitted in is created. Then a hole is created with the operation of "hole" in which these pieces are joined with the tabs of the backrest through two screws ISO 7051 - 4,2 x 25, and by means of a bolt the seat supports are joined to them, allowing the rotation of the seat. Splicing operations are performed to round all edges.

In the lower part, the "Support leg" is screwed using two ISO 4762 M5 x 50 screws, and the "Leg" is screwed using two other ISO 4762 M5 x 50 screws.

Material: steel

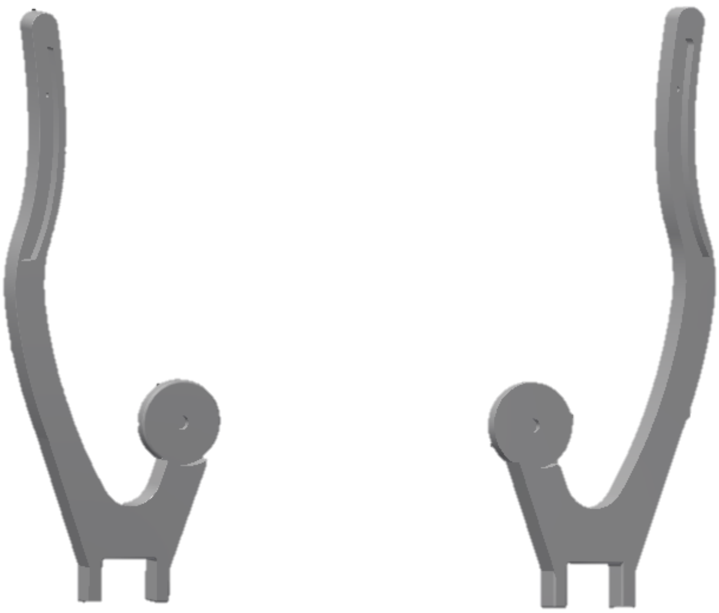


Figure 90: Support backrest left and right ergonomic

Support seat left and right ergonomic

They are respectively called "Left seat support erg" and "Right seat support erg" in Inventor, both made by five extrusion operations, an operation called "hole", and a splice operation. In these pieces the seat tabs are fitted and screwed through to two screws ISO 7046-2 H M4X30, and by means of a bolt they are joined, by the outside of the chair to the supports of the backrest, and on the inside part, to pieces that make the top of both.

Material: steel

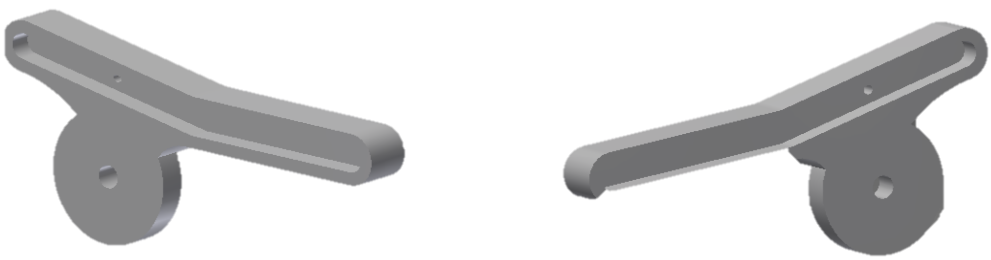


Figure 91: Support seat left and right ergonomic

<u>Interior support, bolt, leg, support leg and bar</u>

In these pieces no modification is made. They are defined in section 4.1.- 3D geometric model with Inventor.

<u>Chair ergonomic assembly</u>

Figure 92 shows the set of all the pieces previously described assembled, forming the whole of the new ergonomic chair.

Figure 92: Chair ergonomic assembly

<u>Table</u>

Figure 93 shows the set of the new table.

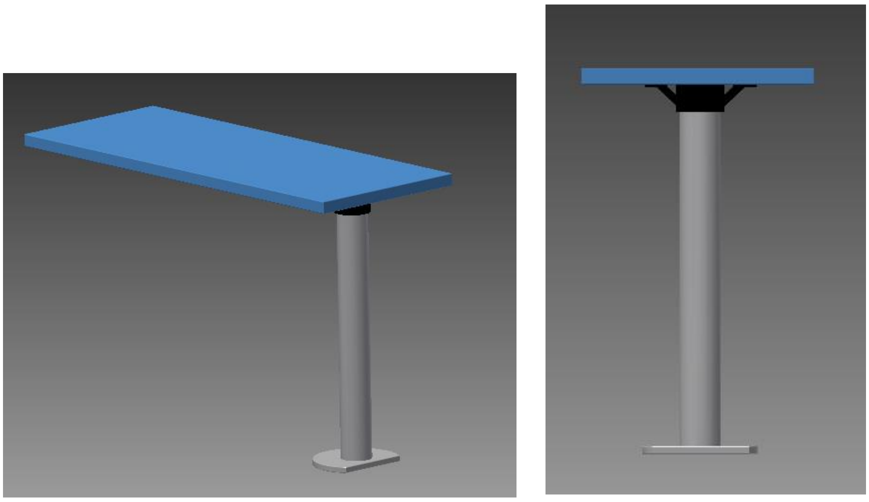


Figure 93: Table ergonomic

Chair and table ergonomic set

Figure 94 shows the set of the chair and table ergonomic.

Figure 94: Chair and table ergonomic set

Ergonomic chairs and table set

The Figure 95 shows the result of the assembly of several ergonomic chairs with the new table also redesigned. In this way we can make an idea of how the new design would be in the classroom.

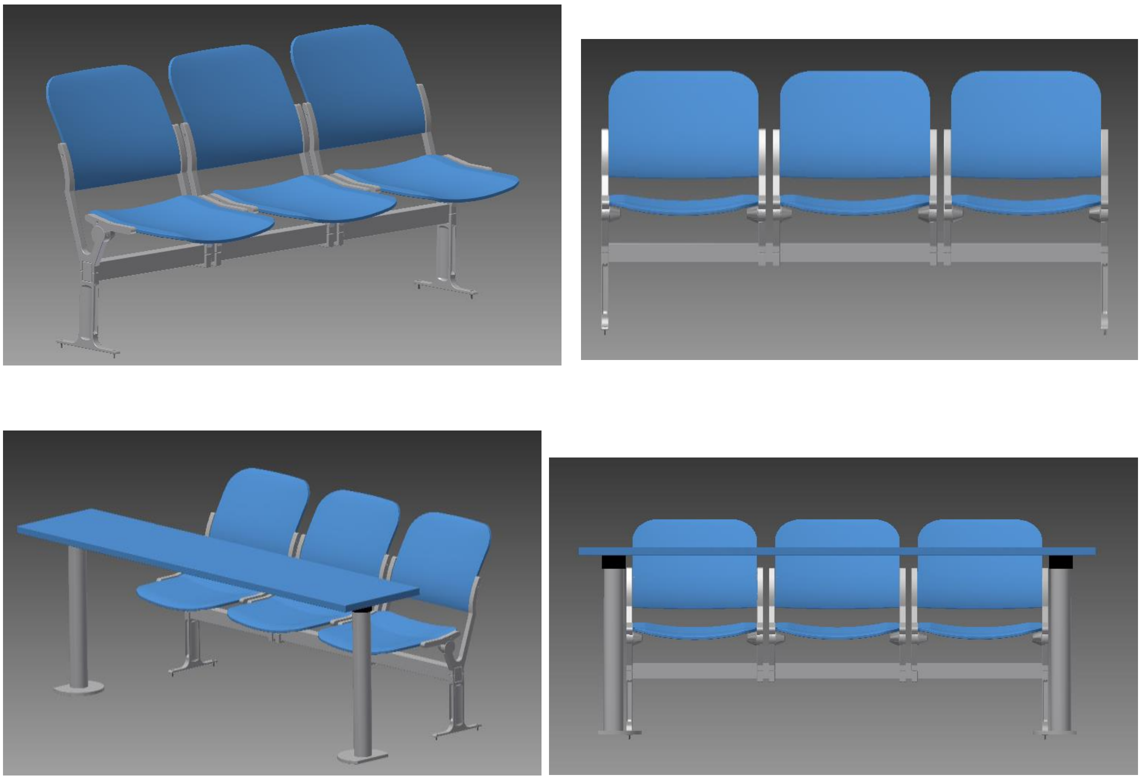


Figure 95: Ergonomic chairs and table set

6.2.- Ergonomic analysis: RULA, REBA, OWAS

The postures that a student of the University of Parma would adopt in the new redesigned chair are studied. Since the chair is a prototype the real posture that a student adopt can not be observed, so it is a theoretical analysis.

In the three methods we will evaluate the normal posture that the user would adopt in the redesigned chair.

6.2.1.- RULA

The method divides the body into two groups. Group A evaluates the position of the upper arm, lower arm and wrist and group B, the position of the neck, trunk and legs.

<u>Group A</u>

Based on the Figure 3 assign a score to each part of the body.

1) Upper arm position: the arm is between 20 degrees of flexion and 20 degrees of extension →+1

   The arm is supported → -1
2) Lower arm position: the lower arm is between 60 and 100 degrees of flexion →+1
3) Wrist position: the wrist is in neutral position → +1
4) The wrist is twisted in mid-range →+1

We enter in Table 2 with the values:

Upper arm = 0
Lower arm = 1
Wrist score = 1
Wrist twist = 1

A provisional score for group A of 1 is obtained, to which as shown in Figure 5 we add the partial score of the static and repetitive posture = +1, and the partial score in the case where loads are involved = 0.

Adding the value obtained in Table 2 together with the partial scores, the final score of group A is obtained.

Final score for group A = +1 +1 +0 = 2

<u>Group B</u>

Based on Figure 4 assign a score to each part of the body.

1) Neck position: the neck is at 0 and 10 degrees of flexion → +1
2) Trunk position: Seated posture, well supported and with an angle trunk-hips >90º→ +0
3) Legs positions: The worker is sitting with legs and feet well supported → +1

We enter in Table 3 with the values:

Neck posture score = 1
Trunk posture score = 0
Legs = 1

A provisional score for group B of 1 is obtained, to which as shown in Figure 6 we add the partial score of the static and repetitive posture = +1, and the partial score in the case where loads are involved = 0.

The final score of group B, will be the sum of the score obtained from Table 3, plus the sum of the partial scores.

Final score for group B = +1 +1 +0 = 2

With the final score for group A = 2 and group B = 2 we enter in Table 4 and obtained the final score for the RULA method of 2, which means that the posture adopted by the user is correct, and no changes are needed.

6.2.2.- REBA

This method divides the body in two groups. Group A that includes the trunk, neck and legs, and the group B, which includes the upper arms, lower arms and wrists.

<u>Group A</u>

Based on Figure 8, to each part of the body a score is assigned.

1) Neck position: the neck is between 10 and 20 degrees of flexion → +1
2) Trunk position: the trunk is erect → +1
3) Legs positions: The worker is sitting with legs and feet well supported → +1

We enter in Table 5 with the values:

Neck posture score = 1
Trunk posture score = 1
Legs = 1

We obtain a provisional score for group A of 1, to which we add the partial of loads. In this case there are no loads, so the score for group A is = 1 + 0 = 1

<u>Group B</u>

Based on the Figure 9 assign a score to each part of the body.

1) Upper arm position: the arm is between 0 and 20 degrees of flexion or 0 and 20 degrees of extension → +1
   The arm is supported → -1
2) Lower arm position: the lower arm is between 60 and 100 degrees of flexion →+1
3) Wrist position: the wrist is in neutral position → +1

We enter in Table 6 with the values:

Upper arm = 0
Lower arm = 1
Wrist score = 1

We obtain a provisional score for group B of 1, to which we add the "Coupling" score, in this case +0. The final score for group B is = 1 + 0 = 1

In Table 7 we enter with the final score of group A = 1 and group B = 1 and obtain a score of 1. To this score, an activity score is added, in this case some body parts are held for longer than 1 minute, so to the score obtained before, we sum +1 (the activity score).

The final score for the REBA method is 1 + 1 = 2, which means that there is a low level of risk, and it is not necessary to make changes at the moment.

6.2.3.- OWAS

The OWAS method evaluates the position of the worker's back, arms, and legs, in addition to the magnitude of the manipulated load
Based on the Figure 11 assign a score to each part of the body.

Back posture: straight → 1
Arms posture: both below shoulder → 1
Legs: sitting → 1
Load: there are no loads → 1

We enter in Table 8 with these scores and get the class that reflects static load risk degree, class 1.

This class 1 means that the user adopts a normal posture, so no intervention is required.

The Table 23, summarizes the postures that the user would adopt in the chair redesigned for each method, as well as the score obtained and their meanings. It also includes the results obtained with these same methods applied to the old chair.

As can be seen, the new chair considerably improves the ergonomic aspects, reducing the risk of the user suffering injuries by adopting the usual study posture in the new chair.

Table 23: Summary of the RULA, REBA and OWAS methods studied for the redesigned chair

		Posture studied	**Score**	**Meaning of the score**
New chair	**RULA**	The normal posture that the user would adopt in the redesigned chair	2	The user adopts a correct posture. No changes are needed.
	REBA	The normal posture that the user would adopt in the redesigned chair	2	Low level of risk, and it is not necessary to make changes at the moment.
	OWAS	The normal posture that the user would adopt in the redesigned chair	1	The user adopts a normal posture. No intervention is required.
Old chair	**RULA**	The one that the user adopts for the most prolonged time	5	More investigations are needed and changes must be done soon.
	REBA	The posture that the user adopts for the most prolonged time and the one that the user should adopt according to the characteristics of the chair	4	There is a medium level of risk, a deeper investigation must be done and changes must be implemented in the chair.
	OWAS	20 different postures	1 or 2	The user adopts a normal posture, so no intervention is required or the posture is slightly harmful and a corrective action should be taken

6.3.- Analysis of mechanical behaviour of the redesigned chair with Inventor

As in the old chair, a mechanical analysis of the redesigned chair modeled is performed with Inventor applying forces in a position and with certain loads according to the UNI-EN 1729-2: 2006 norm. This norm establishes four types of tests to which the chair has to undergo to ensure its resistance. These tests are: forward and sideways stability, rewards stability and seat and back static load of the chair.

The response of the chair to these tests is analyzed, in order to check its resistance.

6.3.1.- Fixation of surfaces

To begin, the necessary surfaces are fixed to avoid the displacement and deformation in them. The lower surface of the leg and the end of the bar are fixed as can be seen in Figure 96.

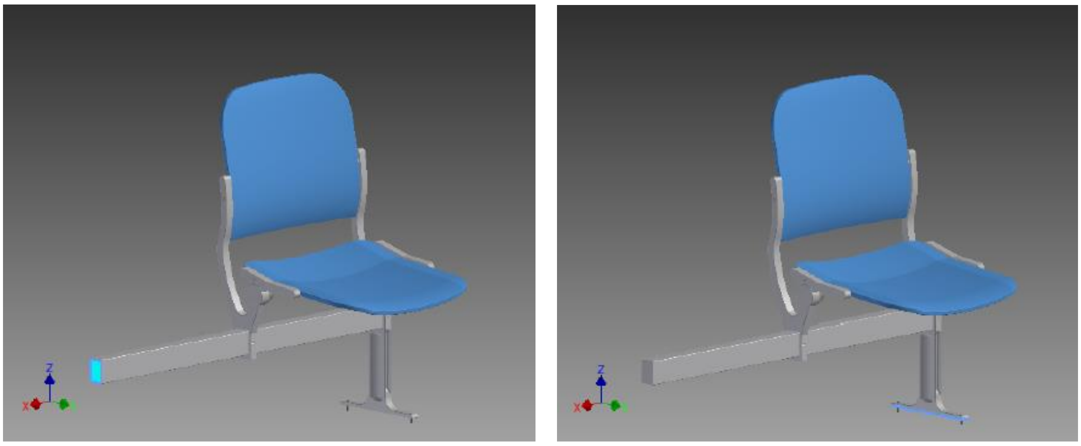


Figure 96: Fixation of surfaces, redesigned chair

6.3.2.- Tests

According to the UNI-EN 1729-2: 2006 norm, it is necessary to apply to the chair four test. These are: forward, sideways and rewards stability, and seat and back static load of the chair.

a. Forward stability of the chair

This first test evaluates the redesigned chair with a load located in the position shown in Figure 16. The applied forces and their position do not vary with respect to the old chair, so they are the same as those described in the Table 16. For the new redesigned chair, these forces are shown in the Figure 97.

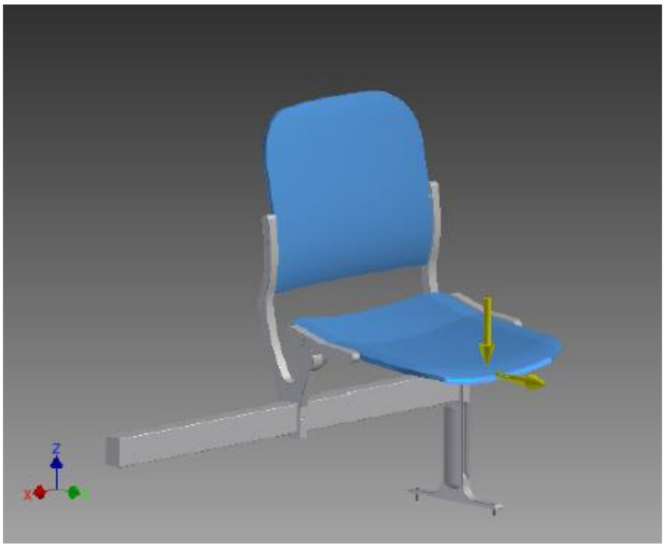


Figure 97: Forces applied in the new chair for the forward stability of the chair test

b. Sideways stability of the chair

Two forces are applied in the position that marks the norm as shown in the Figure 17. As with the previous test, the forces do not vary with respect to the old chair, so they are the same as those described in the Table 17. Figure 98 shows the forces applied in the new redesigned chair.

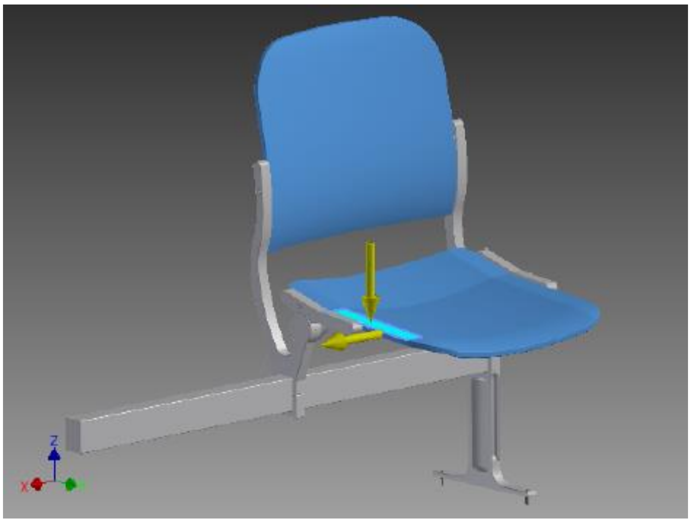


Figure 98: Forces applied in the new chair for the sideways stability of the chair test

c. Rewards stability of the chair

The position that marks the norm for these tests, are shown in the Figure 18. The positions and loads of these forces are shown in the Table 18. For the new redesigned chair, these forces are shown in the Figure 99.

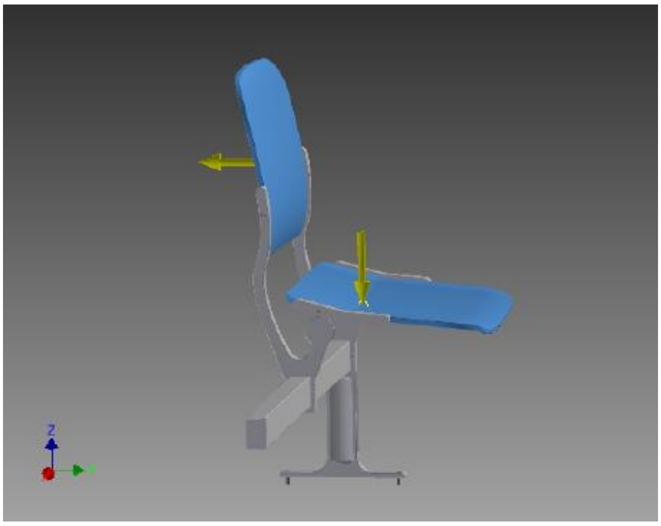


Figure 99: Forces applied in the new chair for the rewards stability of the chair test

e. Seat and back static load of the chair

As shown in the Figure 19, a force in the backrest and in the seat are applied in the determined position as Table 19 shows. These forces applied in the new redesigned chair are represented in Figure 100.

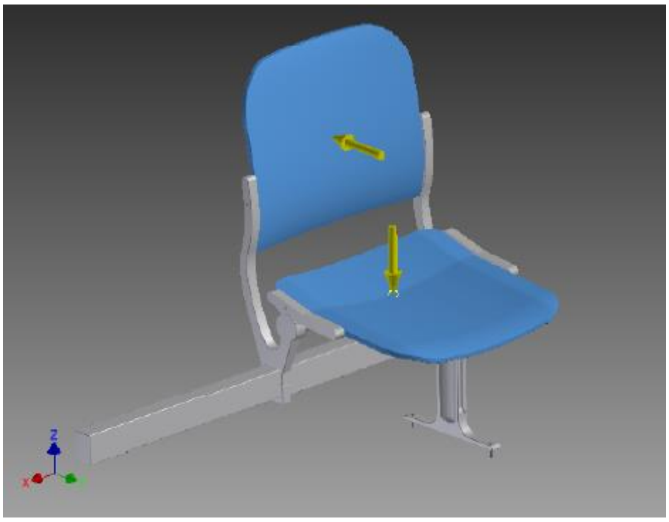


Figure 100: Forces applied in the new chair for the seat and back static load of the chair test

6.3.3.- Results of the study

In order to verify that the redesigned chair responds correctly to the forces applied in it, the following parameters are analyzed:

- Von Mises tensions
- Deformations
- Displacement

a. Von Mises tensions

A Von Mises analysis is performed in each test, in which the maximum effort to which each piece is subjected can be seen. The Table 24 contains the summary of the maximum and minimum efforts collected for each test.

Table 24: Von Mises tensions of the new chair

	Von Mises tensions [MPa]	
	Minimum	**Maximum**
Forward stability	0	583,4
Sideways stability	0	109,4
Rewards stability	0	219,7
Seat and back static load	0	843,9

The maximum tension is given in the test “Seat and back static load”, with a value of 843,9 MPa, since it is the test in which a bigger force is applied, 2000N is applied to the seat.

In the four tests, the maximum Von Mises tension is given in the back and seat clamping screws, so that by changing the choice of the screws, a much lower Von Mises tension value would be obtained.

The following image shows the Von Mises tension graphs for the four tests, Figure 101.

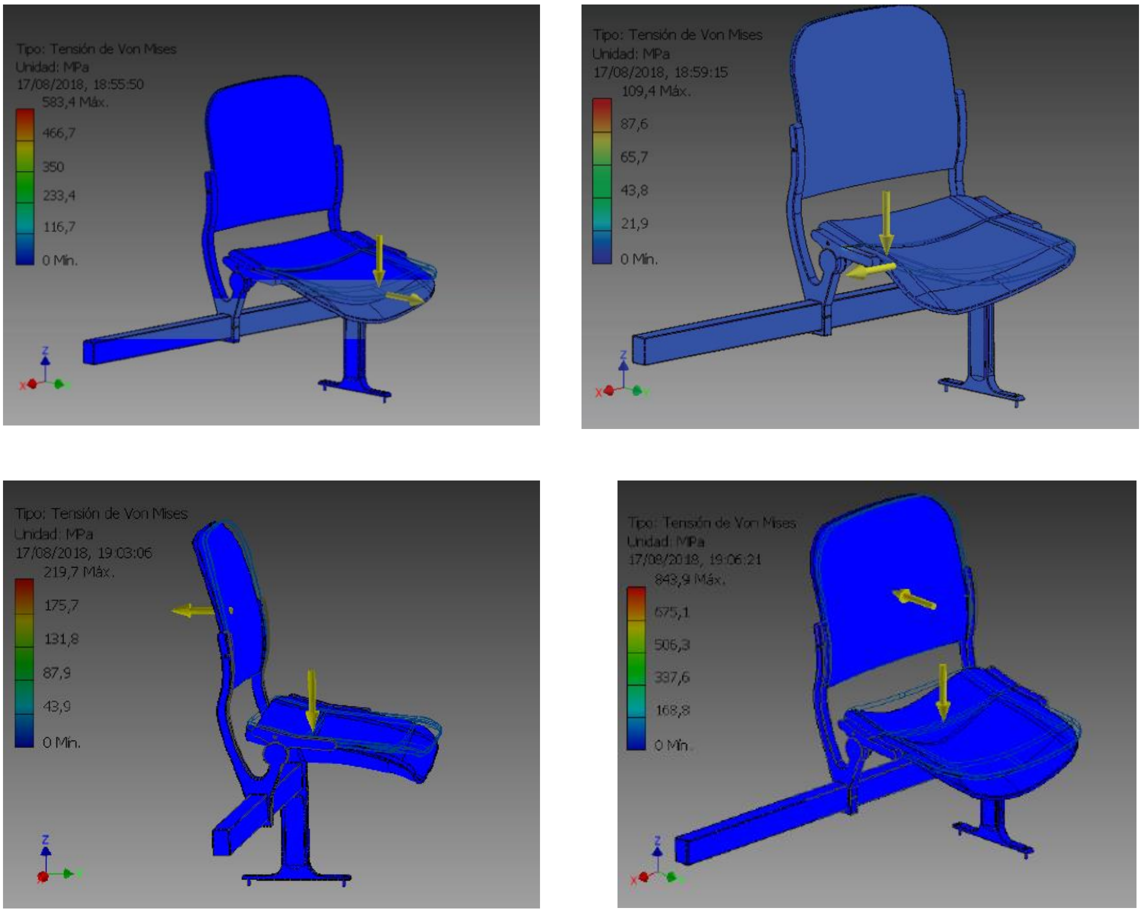


Figure 101: Von Mises graphics of the new chair

As can be seen in the figure, Von Mises' maximum tension in the "forward stability of the chair" test is given in the red zone of the screws that connect the seat with its metal supports, Figure 102.

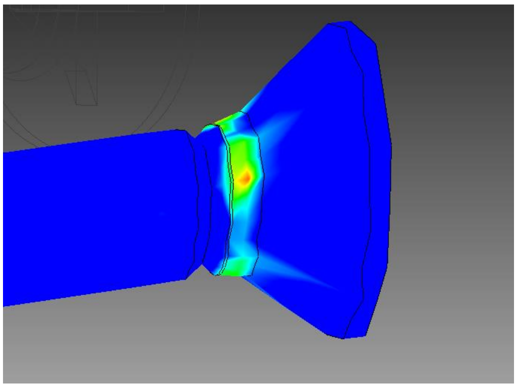


Figure 102: Von Mises' maximum tension in the "forward stability of the chair"

For the second test "sideways stability of the chair" Von Mises maximum tension is given as for the previous test, in the left screw that joins the seat with the metal support, Figure 102. In the Figure 103, it is also seen how there is a Von Mises tension (the light blue area) of an approximate value of 21.9 MPa on the left seat support.

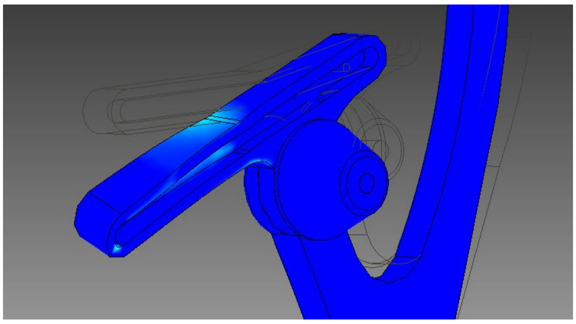


Figure 103: Von Mises tension in the "sideways stability of the chair"

In the case of the test "rewards stability of the chair" the maximum tension of Von Mises is given as in the previous cases, in the screws that join the seat with its supports and in this case, there is also a Von Mises tension in the bolt of approximately 87.9 MPa as can be seen in the Figure 104.

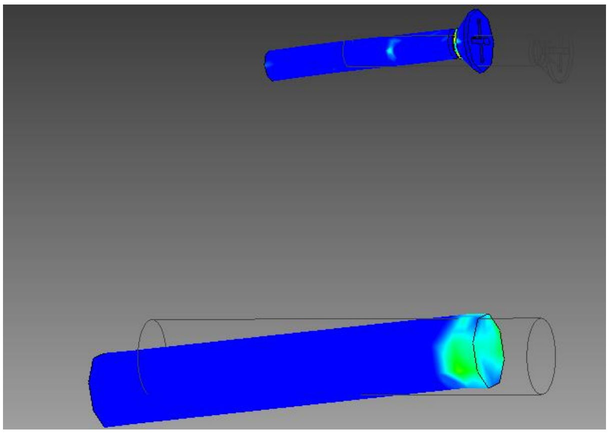


Figure 104: Von mises tension in the “rewards stability of the chair”

Finally, in the "seat and back static load of the chair" test, Von Mises maximum tension is also given in the screws, Figure 102, and there is a zone in the back supports that are subject to an approximate tension of 168,8 MPa, as seen in the Figure 105.

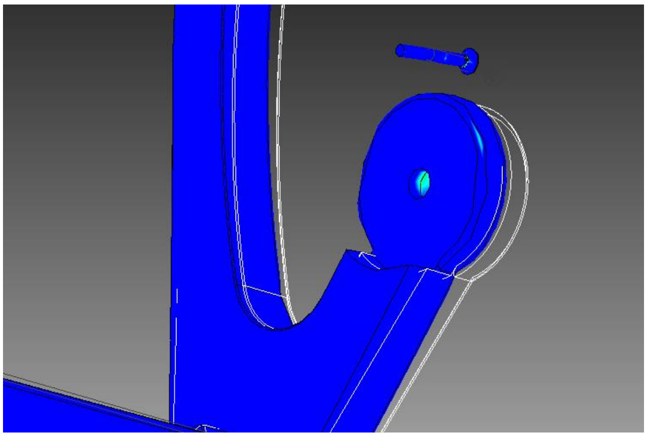


Figure 105: Von Mises tension in the "seat and back static load of the chair"

b. Deformations

Table 25 shows the maximum deformations that the chair suffers depending on the test applied.

Table 25: Deformations of the new chair

	Deformation	
	Minimum	**Maximum**
Forward stability	0	0,027931
Sideways stability	0	0,01725
Rewards stability	0	0,004388
Seat and back static load	0	0,014637

The maximum deformation is 0,027931 and is given in the test "forward stability of the chair".

The Figure 106 shows the graphics of deformation for the four tests.

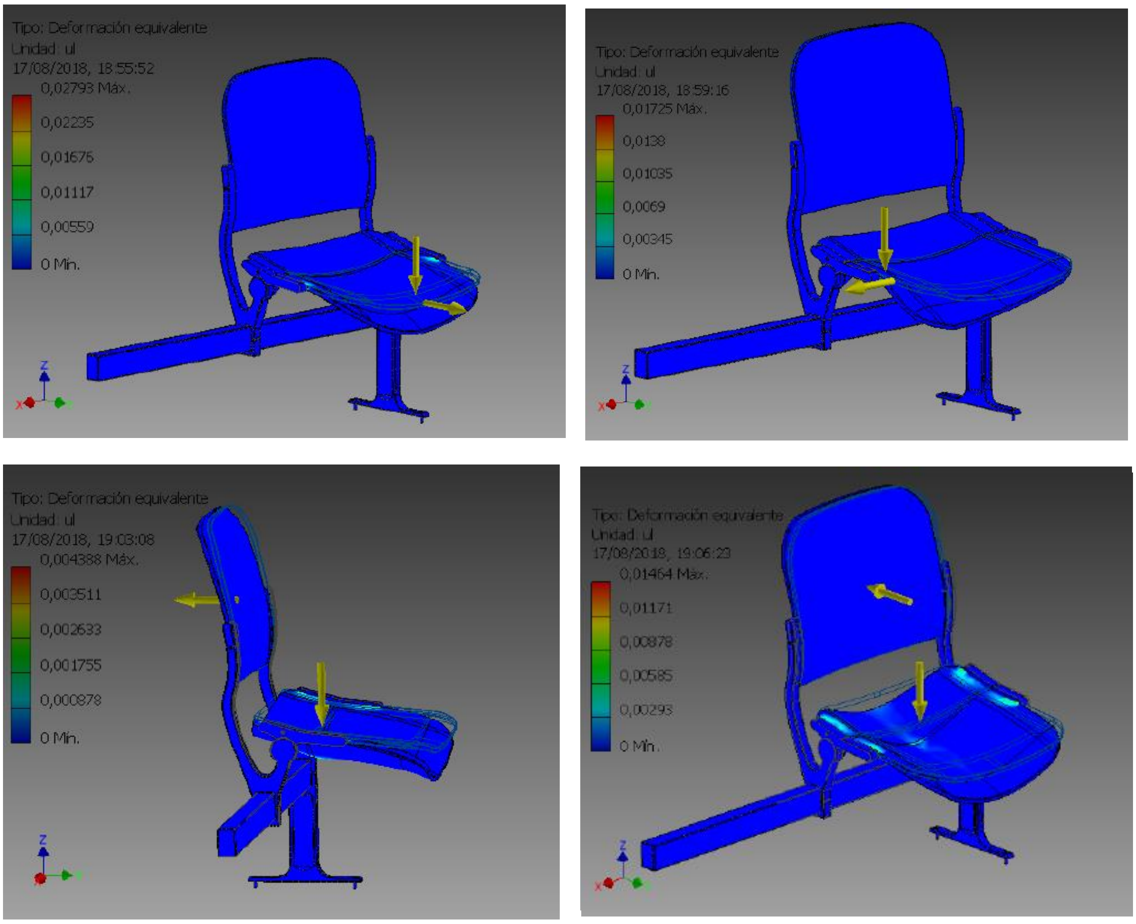


Figure 106: Deformation graphics of the new chair

In the "forward stability of the chair" test the maximum deformation is given in the screws that join the seat with its supports, Figure 107. There is also a slight deformation on the sides of the seat, as shown in the Figure 108.

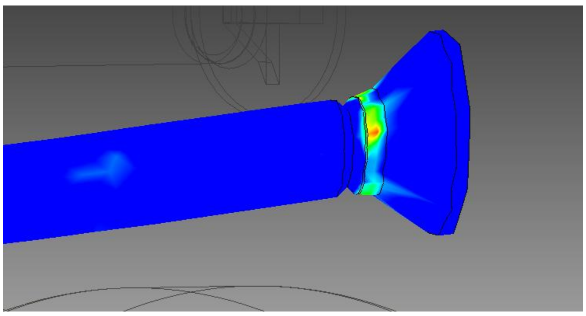


Figure 107: Maximum deformation in the "forward stability of the chair" test

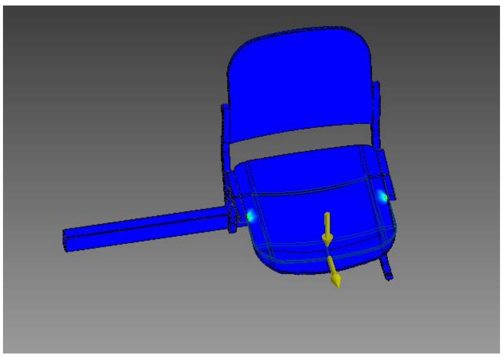


Figure 108: Deformation in the "forward stability of the chair" test

For the "sideways stability of the chair" test, the maximum deformation is given in the screws, as for the previous test, Figure 107.

The Figure 109 shows the maximum deformation (red zone) in the "rewards stability of the chair" test, which is given in the area below the seat. There is also a slight deformation on the sides of the seat (green area) of an approximate value of 0,001755.

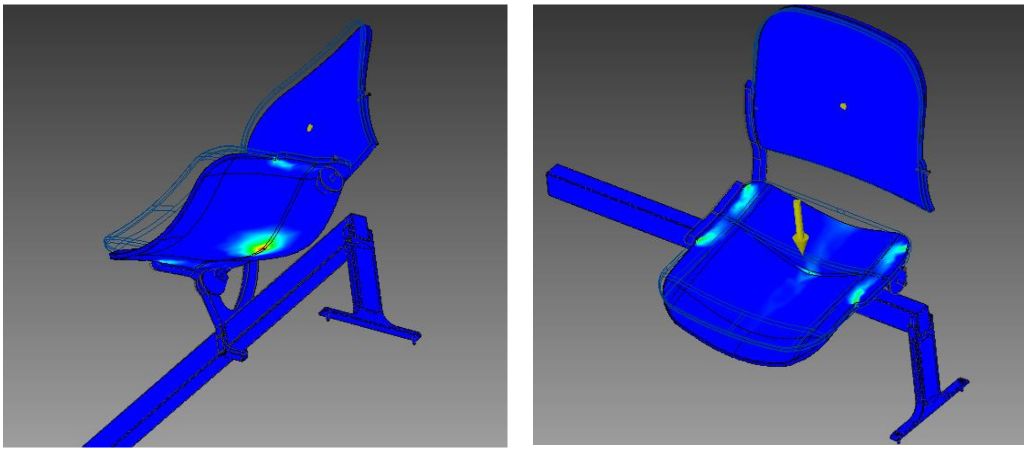


Figure 109: Deformations in the "rewards stability of the chair" test

In the "seat and back static load of the chair" test, the maximum deformation is also given in the area below the seat as shown in Figure 110.

Although polypropylene would support the applied tension, in order to reduce the deformation, the addition of a steel reinforcement on the lower part of the seat could be considered.

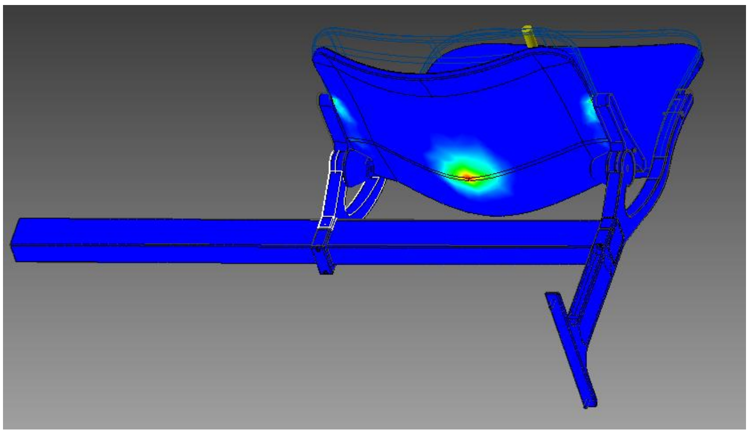


Figure 110: Maximum deformation in the "seat and back static load of the chair" test

c. Displacement

In this case, the Table 26 summaraizes the displacements suffered by the chair depending on the test applied.

Table 26: Displacement of the new chair

	Displacement [mm]	
	Minimum	**Maximum**
Forward stability	0	20,3
Sideways stability	0	5,0
Rewards stability	0	2,9
Seat and back static load	0	9,5

The maximum displacement is 20,3mm, which corresponds to the “forward stability of the chair” test.

The Figure 111 shows the graphics of displacement for the four tests. In the red areas, it is where the maximum displacement is given for each test. In the figure it is seen how the program shows a greater displacement than it is in reality, so that the user can see more easily where and how the greatest displacement occurs.

As in the case of deformation, it could be considered the addition of a steel reinforcement on the lower part of the seat in order to reduce the displacement.

Another possible solution can be the reinforcement of the plastic parts adding reinforcement ribs which are aiming to reduce the overall tensions and so the final displacement.

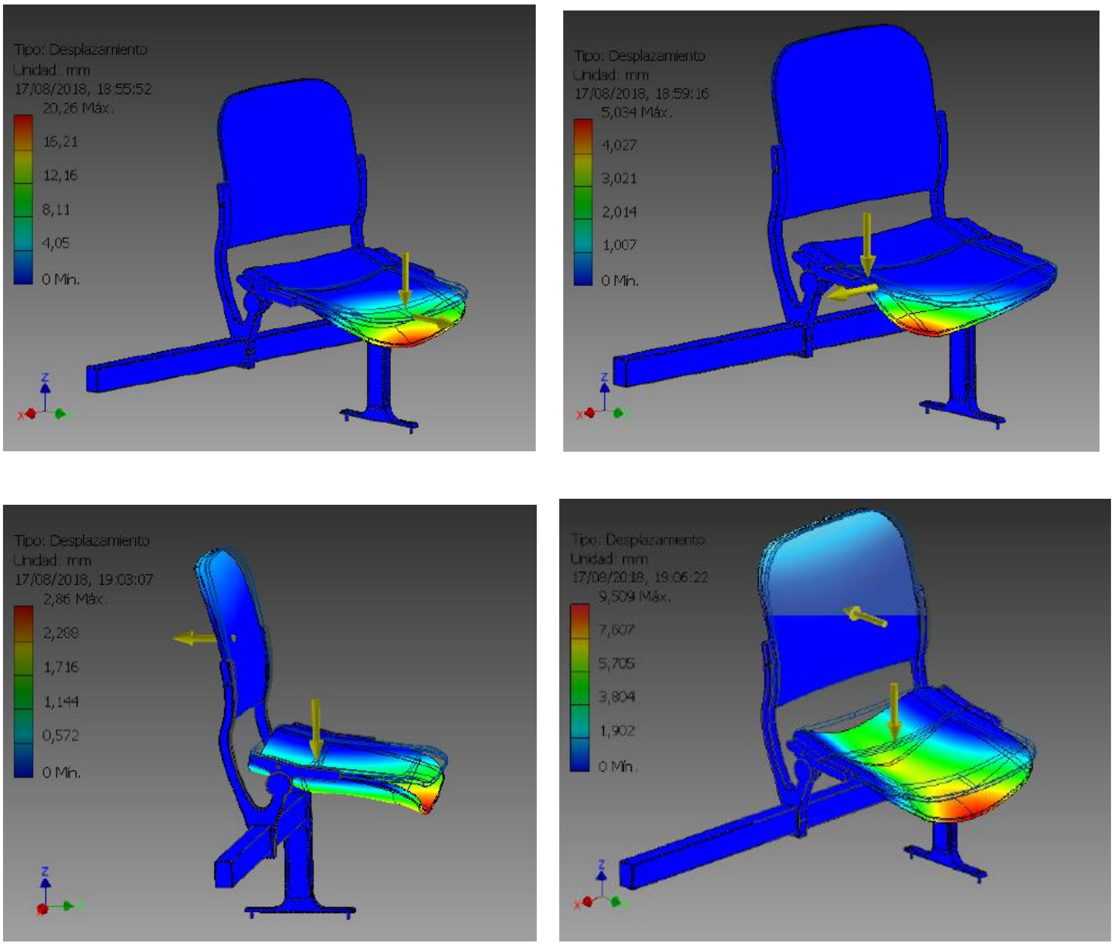


Figure 111: Displacement graphics of the new chair

6.4.- Ergonomic study with Catia

The same ergonomic study with Catia is carried out as the one carried out for the old chair, with the only difference of evaluating the position adopted by the manikin in the new redesigned chair. It begins by designing a manikin whose characteristics are shown in Figure 78.

Once the manikin is created, Figure 79, the new chair is inserted and the manikin is manipulated using the option Standard pose, Posture editor and with the help of the compass until it adopts the desired position in the chair, Figure 112.

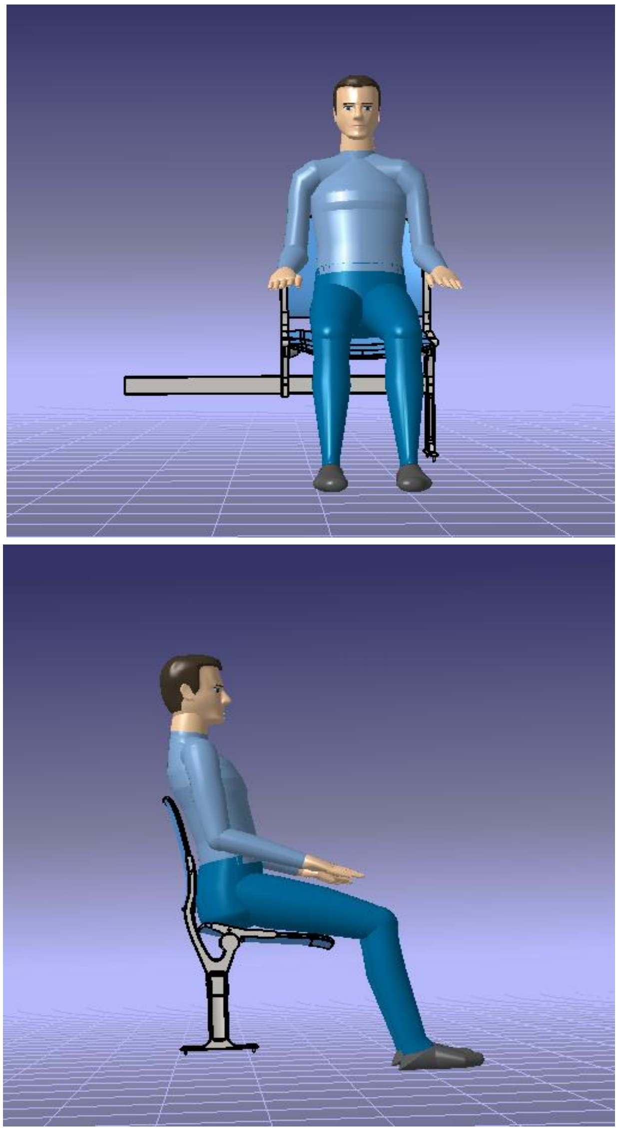


Figure 112: New chair and manikin in Catia

Subsequently, we proceed to evaluate the position adopted through the RULA method, included in the Human Posture Analysis module of the Catia program. The same initial parameters are chosen as for the analysis of the old chair. These are:

- The side to be evaluated: left side.
- Type of posture: repeated
- Arms supported

With these parameters, the program automatically evaluates the posture and, as an output, the score of the RULA method is obtained. In this case, the final score of the

RULA method is 2, which means that the current posture is acceptable and it is not needed any changes.

In the Figure 113, the score obtained by each part of the body, the final score of group A and B, as well as the final score of the RULA method are detailed.

It can be observed that in no part of the body there is a risk of suffering injuries or musculoskeletal disorders except for the "muscle" score, due to a static or repetitive posture, which makes the final score of 2 instead of 1.

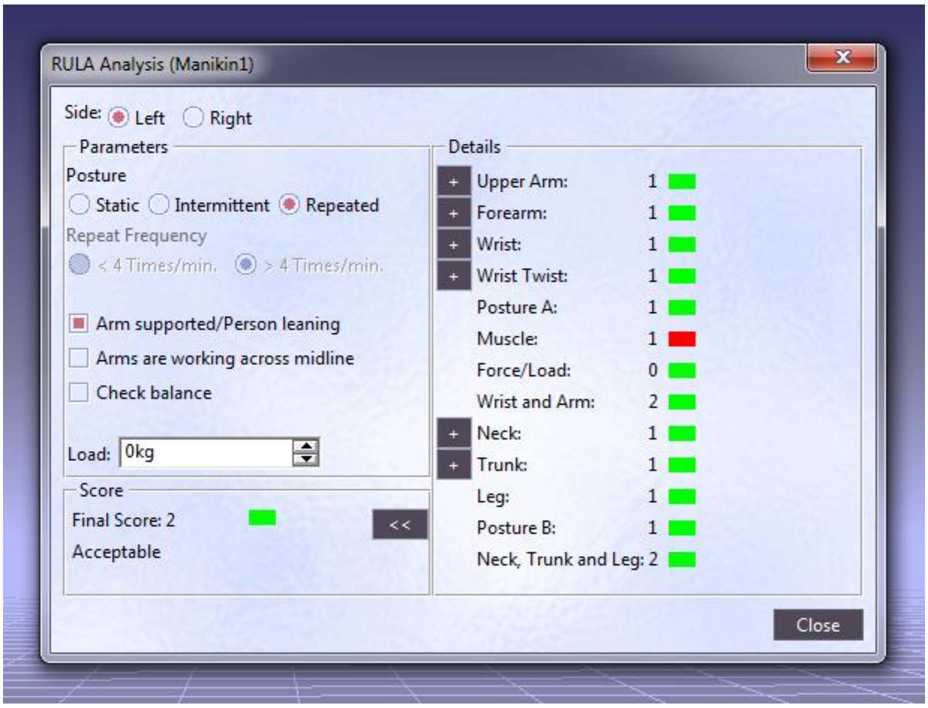


Figure 113: RULA analysis with Catia new chair

7.- Cost analysis

In the study of the cost of the chair, the costs of R+D+I (Research, development and innovation), the manufacture of it and its commercialization are involved. In this cost analysis, only the manufacturing cost of the chair is valued. This analysis is made with the Presto program.

For the study of the manufacturing cost of the chair, an individualized study of the cost of each piece that composes it is carried out. Once the unit values are obtained, the sum of these, gives as output the total cost of manufacturing the chair, without forgetting the costs of quality control of production, which in this case is considered to be 2% of the cost of manufacturing the chair.

Within the individualized study of each piece, depending on it can be broken down into several partial costs such as:

– Manufacturing
– Material
– Screws
– Packaging

This cost study is incorporated as ANNEX I.

In the case of the old chair, the only difference in the cost analysis is in the seat and backrest materials, since they were manufactured with plywood instead of polypropylene. As the cost of the seat and backrest of the new chair is 3,1€ and 3,1€ respectively, this price is considered very low compared to the total of the chair of 35,9€, so although the plywood is a bit more expensive than polypropylene, the cost variation between the two chairs will be very small.

8.- Comparison between old chair and new chair

As can be observed in the Table 27, according to the observational methods RULA, REBA and OWAS, with the new chair a considerable improvement of the ergonomic aspects is obtained in comparison with the old chair, in which the user could get to suffer musculoskeletal disorders due to the posture adopted in it.

This ergonomic improvement is also proved by the ergonomic study carried out with Catia, in which the two chairs with their respective mannequins are submitted to the RULA method.

In reference to the analysis of the mechanical behaviour of both chairs it is observed how the old chair is subjected to minor Von Mises tensions, deformations and displacements. The increase of Von Mises tension in the new chair is due to the choice of screws, so by changing them, this value can be considerably reduced. Regarding the values of deformation and displacement in the new chair, its increase is attributed to the change of the material. Despite this increase, the new chair is able to withstand these efforts, so it would not break.

The main difference between the new chair and the old one is in the backrest and in the seat. As can be seen in Figure 114, the new backrest was designed with a slight prominence that will support the lower back while the seat was designed with an inclination of 15 degrees in the back of the seat and an inclination of 5 degrees in the rest of the seat respect to the horizontal, in such a way that the users will adopt a position where the angle between trunk and thighs is greater than 90 degrees.

Figure 114: Differences between the old chair and the new one

Table 27: Comparison between old chair and new chair

<table>
<tr><th></th><th></th><th>Old chair</th><th>New chair</th></tr>
<tr><td rowspan="3">Observational methods</td><td>RULA</td><td>5</td><td>2</td></tr>
<tr><td>REBA</td><td>4</td><td>2</td></tr>
<tr><td>OWAS</td><td>1 o 2</td><td>1</td></tr>
<tr><td rowspan="3">Analysis of mechanical behaviour with Inventor</td><td>Von Mises tension [MPa]</td><td>257</td><td>843,9</td></tr>
<tr><td>Deformation</td><td>0,0041222</td><td>0,027931</td></tr>
<tr><td>Displacement [mm]</td><td>4,6</td><td>20,3</td></tr>
<tr><td>Ergonomic study with Catia</td><td>RULA</td><td>5</td><td>2</td></tr>
<tr><td rowspan="2">Material</td><td>Seat and backrest</td><td>Plywood</td><td>Polypropylene</td></tr>
<tr><td>Rest of chair pieces</td><td>Steel</td><td>Steel</td></tr>
<tr><td>Cost analysis</td><td>Cost (without VAT) [€]</td><td>35,9</td><td>35,9</td></tr>
</table>

9.- Conclusions

In this thesis an ergonomic study of a chair of the University of Parma has been carried out.

The necessary measures were taken to carry out the 3D modeling of a chair of the University of Parma in Inventor.

The observational methods RULA, REBA and OWAS have been analyzed and are obtained as a result for the old chair 5, 4 and 1 or 2 respectively. According to the results of RULA and REBA, more research is needed and it is necessary to change the design of the chair soon, while the result obtained by the OWAS method indicates that the position adopted by the user is correct and no changes are necessary. This is because this method is not suitable for our study.

In the study of the mechanical behaviour of the old chair made with Inventor a maximum Von Mises tension of 557 MPa, a maximum deformation of 0,0041222, and a maximum displacement of 4,6mm were obtained.

An ergonomic study with Catia has been carried out, in which a result of 5 has been obtained by the RULA method. The same result is obtained as with the RULA observational method, which means that more investigations are necessary and also a modification in the design of the chair.

The critical parameters to be taken into account for the redesign of a new chair were analyzed. These parameters are: seat height, seat width, angle between thighs and trunk, free space or curvature in the seat, position of the arms with respect to the trunk and rounding edges.

A redesign of the chair is carried out, in which the main modifications are made to the backrest and the seat, modifying the materials and their shape, thus improving the ergonomic aspects of the new chair.

In the studies of the RULA, REBA and OWAS observational methods applied to the new chair, values of 2, 2 and 1 were obtained respectively, which means that there is a low level of risk, and it is not necessary to make changes in the chair.

A study of the mechanical behavior of the new chair in which it was obtained a maximum Von Mises tension of 843,9 MPa which was given in the test “Seat and back static load”, since it is the test in which a bigger force is applied, (2000N is applied to the seat), a maximum deformation of 0,027931, and a maximum displacement of 20,3 mm, both given in the “forward stability of the chair” test.

The high results of the Von Mises tension as well as the displacement could be reduced by changing the screws, the material of the seat and backrest or by improving the geometry of the sides of the chair to guarantee the safety of the students. These variations will be studied in depth in future work.

An ergonomic study has been carried out on the new chair with Catia, in which a result of 2 has been obtained by the RULA method, as with the RULA observational method, which means that it is not necessary to make any changes to the new chair. This confirms that there has been an improvement in the ergonomics of the chair with respect to the old chair.

Finally, a study of the cost of the new chair in which a total cost of 43,42 € (including the VAT) was obtained.

10.- Bibliography

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ERGONOMIC CHAIR

MANUFACTURE OF ERGONOMIC CLASSROOM CHAIR FOR UNIVERSITY

Within the phases of manufacturing the chair, we find several stages of the process, which have to be assessed to obtain the final cost of the chair. In this estimation a single unit is considered, mounted in modules of three chairs, therefore the cost of the leg and the bar is divided between three.

MANUFACTURING:

For the manufacture of the chair, two basic materials are used, polypropylene and steel.

The chair is composed of the following elements:

POLYPROPYLENE

1 Polupropylene seat

2 Polypropylene backrest

STEEL

3 Support backrest left and right ergonomic

4 Support leg

5 Support seat left and right ergonomic

6 Steel bolt

7 Interior support

8 Steel leg (1/3 unit per seat is considered)

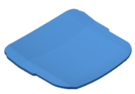
9 Steel bar (1/3 unit per seat)

10 Assembly chair installation

CAPÍTULO 01 MANUFACTURE OF ERGONOMIC CHAIR

01.01

Polypropylene seat



Manufacture of monobloc seat, molded by injection in plastic (polypropylene), in color. Matte surface, molded in 12 mm thick ergonomic design.

01.02

Polypropylene backrest

Manufacture of monobloc backrest, molded by injection in plastic (polypropylene), in color. Matte surface, molded in 12 mm thick ergonomic design.

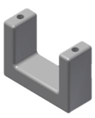
01.03

Support backrest left and right ergonomic

Support backrest left and right ergonomic in cast steel, including mounting and packing screws.

01.04

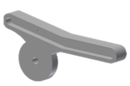
Support leg



Steel leg bracket with screw fixings type ISO 4762 M5 x 50. Packaging.

01.05

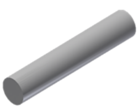
Support seat left and right ergonomic



Support seat left and right ergonomic made of cast steel, including mounting and packing screws.

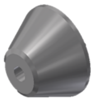
01.06

Steel bolt



Steel bolt, made by an foundry operation.

01.07



Interior support

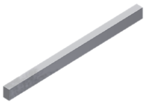
Steel interior support made by an foundry operation.

01.08

Steel leg

Steel leg for support every three seats, including fixing screws.

01.09



Steel bar

Steel bar to make the union between the chairs that are located in the same row.

01.10

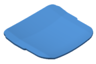
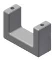
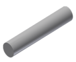
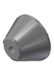
Assembly chair installation.

Labor cost for the assembly of the chair and its installation, including the proportional part of the auxiliary material and auxiliary means.

CAPÍTULO 02 QUALITY CONTROL

	Manufacturing quality control estimated at two percent of the cost.
02.01	**Quality Control 2%**

ERGONOMIC CHAIR

CODE	SUMMARY	UDS	PARTIAL	QUANTITY	PRICE	AMOUNT
	CHAPTER 01 MANUFACTURE OF ERGONOMIC CHAIR					
01.01	u **Polypropylene seat**					
	Manufacture of monobloc seat, molded by injection in plastic (polypropylene), in color. Matte surface, molded in 12 mm thick ergonomic design.					
		1	1,0000			
				1,0000	3,1475	3,1475
01.02	u **Polypropylene backrest**					
	Manufacture of monobloc backrest, molded by injection in plastic (polypropylene), in color. Matte surface, molded in 12 mm thick ergonomic design.					
		1	1,0000			
				1,0000	3,1000	3,1000
01.03	u **Support backrest left and right ergonomic**					
	Support backrest left and right ergonomic in cast steel, including mounting and packing screws.					
	right	1	1,0000			
	left	1	1,0000			
				2,0000	2,6310	5,2620
01.04	u **Support leg**					
	Steel leg bracket with screw fixings type ISO 4762 M5 x 50. Packaging.					
	right	1	1,0000			
	left	1	1,0000			
				2,0000	2,3300	4,6600
01.05	u **Support seat left and right ergonomic**					
	Support seat left and right ergonomic made of cast steel, including mounting and packing screws.					
	right	1	1,0000			
	left	1	1,0000			
				2,0000	2,4970	4,9940
01.06	u **Steel bolt**					
	Steel bolt, made by an foundry operation.					
		2	2,0000			
				2,0000	0,4200	0,8400
01.07	u **Interior support**					
	Steel interior support made by an foundry operation.					
		2	2,0000			
				2,0000	0,5500	1,1000
01.08	u **Steel leg**					
	Steel leg for support every three seats, including fixing screws.					
	For the instalation of three seats	0,33	0,3300			
				0,3300	4,7460	1,5662
01.09	u **Steel bar**					
	Steel bar to make the union between the chairs that are located in the same row.					
	For the instalation of three seats	0,33	0,3300			
				0,3300	4,6600	1,5378

CODE	SUMMARY	UDS	PARTIAL	QUANTITY	PRICE	AMOUNT
01.10	u **Assembly chair installation.**					
	Labor cost for the assembly of the chair and its installation, including the proportional part of the auxiliary material and auxiliary means.					
		1	1,0000			
				1,0000	8,9740	8,9740
	TOTAL CHAPTER 01 MANUFACTURE OF ERGONOMIC CHAIR					**35,1815**

CODE	SUMMARY	UDS		PARTIAL	QUANTITY	PRICE	AMOUNT
	CHAPTER 02 QUALITY CONTROL						
02.01	**u Quality Control 2%**						
	Coste fabricación	1	35,0462	35,0462			
					35,0462	0,0200	0,7009
	TOTAL CHAPTER 02 QUALITY CONTROL						**0,7009**
	TOTAL						**35,8824**

ERGONOMIC CHAIR

CHAPTER	SUMMARY	EUROS	%
1	MANUFACTURE OF ERGONOMIC CHAIR	35,1815	98,05
2	QUALITY CONTROL	0,7009	1,95
	MANUFACTURING UNIT COST	**35,8824**	
	21,00 % I.V.A.	7,5353	
	FINAL GENERAL BUDGET	**43,4177**	

INCREASE THE BUDGET OF GENERAL MANUFACTURING TO THE EXPRESSED AMOUNT OF FORTY THREE EUROS WITH FORTY ONE CENTS

CODE	QUANTITY	UD	SUMMARY	PRICE	SUBTOTAL	AMOUNT
CHAPTER 01 MANUFACTURE OF ERGONOMIC CHAIR						
01.01		u	**Polypropylene seat**			
			Manufacture of monobloc seat, molded by injection in plastic (polypropylene), in color. Matte surface, molded in 12 mm thick ergonomic design.			
FABRI01	1,0000	u	Manufacture piece by injection	1,5000	1,5000	
POLIPR01	0,0021	m³	Bulk polypropylene	475,0000	0,9975	
EMBAL.01	1,0000	u	Packaging	0,6500	0,6500	
			TOTAL COST			**3,1475**
THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF THREE EUROS WITH FOURTEEN CENTS						
01.02		u	**Polypropylene backrest**			
			Manufacture of monobloc backrest, molded by injection in plastic (polypropylene), in color. Matte surface, molded in 12 mm thick ergonomic design.			
FABRI01	1,0000	u	Manufacture piece by injection	1,5000	1,5000	
POLIPR01	0,0020	m³	Bulk polypropylene	475,0000	0,9500	
EMBAL.01	1,0000	u	Packaging	0,6500	0,6500	
			TOTAL COST			**3,1000**
THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF THREE EUROS WITH TEN CENTS						
01.03		u	**Support backrest left and right ergonomic**			
			Support backrest left and right ergonomic in cast steel, including mounting and packing screws.			
FABRI02	1,0000	u	Support backrest left and right ergonomic	1,8710	1,8710	
TORNI.01	1,0000	u	Screws ISO 7051 - 4,2 x 25	0,1100	0,1100	
EMBAL.01	1,0000	u	Packaging	0,6500	0,6500	
			TOTAL COST			**2,6310**
THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF TWO EUROS WITH SIXTY THREE CENTS						
01.04		u	**Support leg**			
			Steel leg bracket with screw fixings type ISO 4762 M5 x 50. Packaging.			
FABRI03	1,0000	u	Cast steel staple	1,7500	1,7500	
TORNI.02	2,0000	u	ISO 4762 M5 x 50 screws	0,1400	0,2800	
EMBAL.02	1,0000	u	Embalaje grapa	0,3000	0,3000	
			TOTAL COST			**2,3300**
THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF TWO EUROS WITH THIRTY THREE CENTS						
01.05		u	**Support seat left and right ergonomic**			
			Support seat left and right ergonomic made of cast steel, including mounting and packing screws.			
FABRI.04	1,0000	u	Support seat left and right ergonomic	1,7420	1,7420	
TORNI.03	1,0000	u	screws ISO 7046-2 H M4X30	0,1050	0,1050	
EMBAL.01	1,0000	u	Packaging	0,6500	0,6500	
			TOTAL COST			**2,4970**
THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF TWO EUROS WITH FORTY NINE CENTS						
01.06		u	**Steel bolt**			
			Steel bolt, made by an foundry operation.			
FABRI..05	1,0000	u	Steel bolt	0,2700	0,2700	
EMBAL.05	1,0000	u	Packing	0,1500	0,1500	
			TOTAL COST			**0,4200**
THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF CERO EUROS WITH FORTY TWO CENTS						
01.07		u	**Interior support**			
			Steel interior support made by an foundry operation.			
FABRI.06	1,0000	u	Interior support	0,4000	0,4000	
EMBAL.05	1,0000	u	Packing	0,1500	0,1500	
			TOTAL COST			**0,5500**
THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF CERO EUROS WITH FIFTY FIVE CENTS						

CODE	QUANTITY	UD	SUMMARY	PRICE	SUBTOTAL	AMOUNT
01.08		**u**	**Steel leg**			
			Steel leg for support every three seats, including fixing screws.			
FABRI.07	1,0000	u	Steel leg	3,8700	3,8700	
TORNI.04	2,0000	u	screws ISO 4762 M5 x 50	0,1130	0,2260	
EMBAL.01	1,0000	u	Packaging	0,6500	0,6500	
			TOTAL COST			**4,7460**

THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF FOUR EUROS WITH SEVENTY FOUR CENTS

CODE	QUANTITY	UD	SUMMARY	PRICE	SUBTOTAL	AMOUNT
01.09		**u**	**Steel bar**			
			Steel bar to make the union between the chairs that are located in the same row.			
FABRI.08	1,0000	u	Steel bar	4,2500	4,2500	
EMBAL.03	1,0000	u	Packing	0,4100	0,4100	
			TOTAL COST			**4,6600**

THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF FOUR EUROS WITH SIXTY SIX CENTS

CODE	QUANTITY	UD	SUMMARY	PRICE	SUBTOTAL	AMOUNT
01.10		**u**	**Assembly chair installation.**			
			Labor cost for the assembly of the chair and its installation, including the proportional part of the auxiliary material and auxiliary means.			
MOO.01	0,2500	h	Official installer	18,0000	4,5000	
MOO.02	0,2500	h	Installer assistant	16,0000	4,0000	
%0300	3,0000	%	Auxiliary material	8,5000	0,2550	
%0250	2,5000	%	Auxiliary means	8,7600	0,2190	
			TOTAL COST			**8,9740**

THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF EIGHT EUROS WITH NINETY SEVEN CENTS

CODE	QUANTITY	UD	SUMMARY	PRICE	SUBTOTAL	AMOUNT
CHAPTER 02 QUALITY CONTROL						
02.01		u	**Quality Control 2%**			
				Sin descomposición		
			TOTAL COST			**0,0200**

THE TOTAL PRICE OF THE ITEM INCREASES TO THE AMOUNT OF CERO EUROS WITH TWO CENTS