Politecnico di Milano

Design Methods

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The Americas and Italy by Design

Project:
Design of Workspace for Prototyping
Final Report

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Abstract:

In the following pages is shown the whole process that has led us to the concept of the design of a Prototyping Workstation that can be used by workers with different disabilites from the gathering of some ideas to the final version ready for the costumer with all the specifications defined.

Index:

1. Introduction

1.1 Initial Problem Statement

The initial problem we are facing is creating a facility that is limited to 360 square feet of space and that may have the conditions for four persons, with different kind of disabilities, can work and do a prototype using its tools, machines and tables. Some of the disabilities are paraplegia, amputation, muscular dystrophy and cardiac conditions. The space inside the workstation must be enough for everyone to move around, work and even to help each other. The workstation must have different kind of tools and has to be made in a way that any kind of worked can use them.

1.2 Initial Considerations

The first restriction we are facing is the one due to the small space available, every decision we are making must not break this restriction, so from tables to the prototyping machine, everything has to be study carefully in a way that everyone can move and have space to realize every task.
The other problem we are facing are the disabilities of the workers: we have to take into account solutions in order to make up for reduced mobility, cardiac problems, lack of force and so on. So we will need an extremely flexible workstation: both from the machine to the tables and tools should be as flexible (adaptable) as possible in order to reduce movements of the workers.
Then we will focus also on what we have to prototype: door latch. We will try to divide the whole prototyping process in different steps and try to split them along the whole working path inside the workstation focusing also on which part will be more suitable to be done by each worker.

In the following tables are listed some of our major considerations about the design problem we have to solve.

1.3 Machines table

Table 1: Principal requirements of each equipment

Equipment	Problems	Needs
Prototyping machine	Dimensions / Fitting /	Big dimensions
Assembly Tables	Dimensions /Fitting / Adaptable	Workers have to be able of using their hands
Assembly Tools	Flexible	Hand tools / They have to be reachable and at table level
Conveyor Belt	Dimensions/ Fitting/ Adaptable	Space

1.4 Justification of Machine types selected

- Prototyping machine: is computer controlled machine in which the operator must put a polymeric material inside and then it will give a shape melting the material. This shape, though, will have to be, eventually refined by further processes.
  An example of this machine is shown here below:

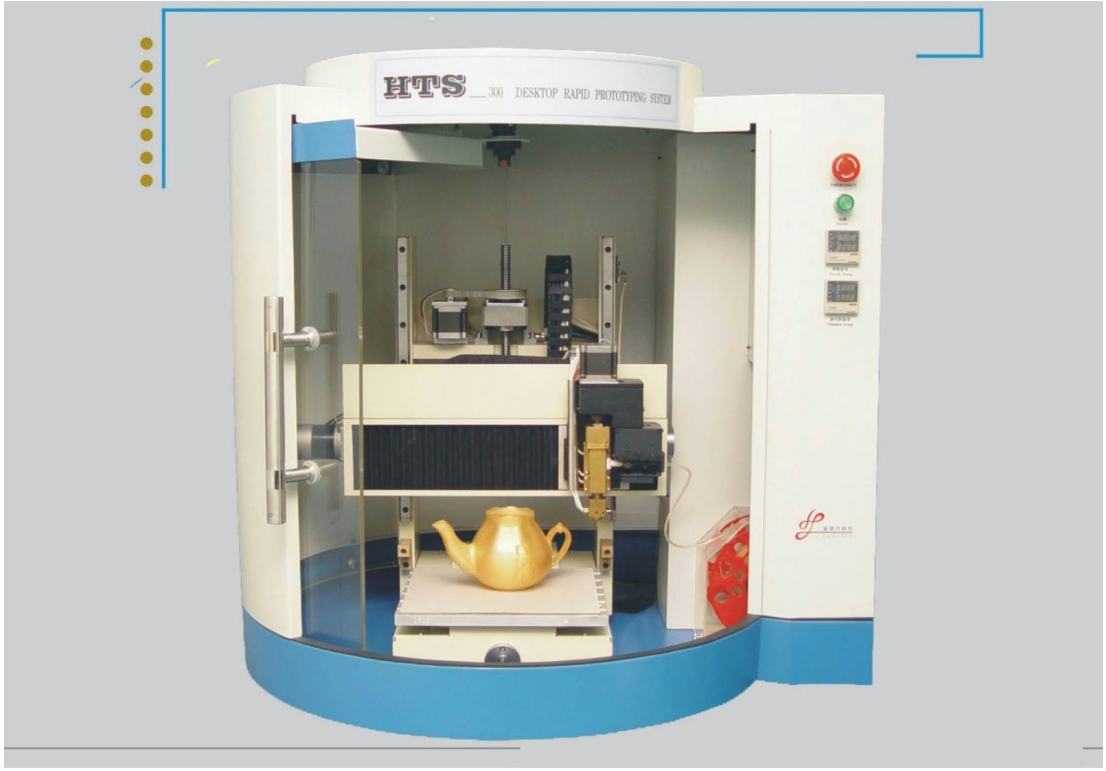


Figure 1: Example of prototyping machines

- Assembly-refining table 1: is a table for a first assembly and a refining the parts that we obtain from the prototyping machine;
- Assembly table two: is a table to do the assembly the different parts of the door latch
- Assembly table three: is the table were we joint the two half's of the prototype

1.5 Disabilities Table

When we work with the classification of disabilities is complicated to evolve all the different kind of characteristics that define a specific situation. In order to simplify the design for this first approach, we have decided to reduce the range of disabilities, trying to select those that are the most common disabilities in workplaces. With this simplification, we are more able to design tools and spaces that cover the principal needs of users with some other similar disabilities.

Table 2: Principal characteristics of disabilities

Disability	Position	Description
Paraplegia	Assembly table 1	No movement of legs.
Amputation	Feeding and shaping	Missing a part of the body
Muscular Dystrophy	Assembly table 2	Low force in the limbs
Cardiac Conditions	Assembly table 3	Difficult to breath and move too much

1.5.1 Justification in the decision of the job chosen for each disability:

- Paraplegia: We decided to put this disability in Assembly table one because, to do this kind of work the employee doesn't need to move much, because all the parts needed are already been sent to the workstation.
- Amputation: We decided to put this the person with this disability doing the feeding and the starting of the CNC machine and helping the other workstations, because the parts needed in this job are light and a person with this disability can do this, even if it's missing a leg or an arm.
- Muscular Dystrophy: We decided to put this disability in Assembly table two because he doesn't need to use heavy force and you don't need to move too much.
- Cardiac Conditions: We decided to put this disability in Assembly table three because in this part of the work the worker may require to be a little higher, but he doesn't need to move too much, and it may require some strength and because there will be a special attention from the worker in the CNC machine.

1.6 Object to be produced attributes

The door latch is composed by two equal major parts, like the one in the picture, with small parts within it, than in the end are joined by a joint process like Screw joint.

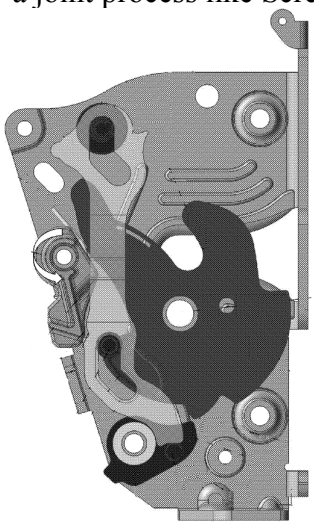


Figure 2: Door latch assembly geometry

Each half has small parts that are joined to the bigger part, with the help of tools, almost all the small part are done in the CNC machine and before they are joined to the big part each of them, including the big part, has to be submitted to superficial treatment processes with the help of sandpaper or other tools. The only thing that is not printed is the wire needed to do the connection with the door and the door latch, that one is joined in the part, with the other small parts.

2. Customer and product requirements:

In this paragraph we are going to analyse the main requirements of our workstation: we are going to put in together what the customer wants and also the main restriction we have been given both the direct and indirect ones. Thus the main goal will be to have a requirement and constraint lists.

2.1 Minimum requirements:

The minimums include:

- Lift system to be able to reach further back on the workbench
- Ventilation/ airflow to keep from breathing in specks of dust
- Detector of negative health aspects
- Wheelchair accessible facility
- People working inside the workstation must be able to help each other's

2.2 Table of Constraints:

From the minimum requirements we have extrapolated a series of constraints that are going to influence the design of our workstation.
These are shown in the table here below:

Table 3: Design constraints

Safety	**Space utilization**	**Performance**	**Costs**
Guard protection while in operation First aid kit Emergency contacting device Safety Plan Safe environment Course of first aid Penny button	Regulated tables and conveyor (Reach) Ergonomics Easy access	High efficiency High reliability Auto feeding-conveyor Emergency stop button	Minimal cost to customers Low maintenance cost

We first looked at safety because the workers are the ones who are at the centre of our design. We have a very particular kind of workers that requires extra-care and for this reason we have placed all these required objects.
Then we wanted to deal with space utilization that, as stated before, is a big constraint we have and we have placed the main feature we must provide.
For our costumer, also performance is a very important indicator and so it must be satisfied in order to have our product competitive in the market.
Related to the capability of our product to be successful in the market we also have constriction with cost both the product cost and the maintenance one.

3. Objectives

3.1 Weighting of Attributes

As the workstation has to be adapted to permit disabled persons to work in it, we have summarized the most critical objectives that we should have in mind when we design it, permitting us having a better workstation, with better working, safety and production conditions.
So to do that we create an index with which we are going to define each objective of our product in the AHP Pairwise Comparison as shown in the table here below:

Table 4: Objective s hierarchy

1. Safety 1.1 Guard protection while in operation 1.2 First aid kit 1.3 Emergency contacting device 1.4 Safety Plan 1.5 Safe environment 1.6 Course of first aid
2. Space utilization 2.1 Regulated tables and conveyor (Reach) 2.2 Ergonomics 2.3 Easy access
3. Performance 3.1 High efficiency 3.2 High reliability 3.3 Auto feeding- conveyor 3.4 Emergency stop button
4. Cost 4.1 Minimal cost to customers 4.2 Low maintenance cost

Then using the created index we are going to start the AHP Pairwise Comparison Chart as displayed in the following tables.

3.2 AHP Pairwise Comparison Chart

Table 5: General Analytic Hierarchy Process

	Safety	Space utilization	Performances	Cost	Total	Weight
Safety	1.00	1.50	2.00	2.50	7	0.39
Space utilization	0.67	1.00	1.33	1.67	4.67	0.26
Performances	0.50	0.75	1.00	1.25	3.5	0.19
Cost	0.40	0.60	0.8	1.00	2.8	0.16
					17.97	1.00

Following what we have said before we decide to create a scale to evaluate our attribute. The safety attribute will be the most important with a weight of 1. This is because nobody would ever want a workstation where safety is not fully guaranteed.

We have decided to give 0.67 to space utilization because we consider it our most critical constrain and every attribute that can contribute to better use space must be seriously taken into account.

Then, at the end, we have given 0.5 and 0.4 to performance and cost. These are the lowest weights we assign because are not the main factors of our design. Is to be said that these are factors that helps our workstation to be more competitive in the market, more we can satisfy them, more the workstation will be easy to be sold but are not vital factor for our workstation.

Table 6: Analytic Hierarchy Process (Safety)

	Safety (0.39)						Total	Relative Weight	Absolute Weight
Safety	1.1	1.2	1.3	1.4	1.5	1.6			
1.1	1.00	1.00	0.67	2.00	1.75	2.50	8.92	0.20	0.08
1.2	1.00	1.00	0.67	2.00	1.75	2.50	8.92	0.20	0.08
1.3	1.50	1.50	1.00	2.50	2.25	3.00	11.75	0.27	0.11
1.4	0.50	0.50	0.40	1.00	0.75	1.50	4.65	0.11	0.04
1.5	0.57	0.57	0.44	1.33	1.00	2.00	5.91	0.14	0.05
1.6	0.40	0.40	0.33	0.67	0.50	1.00	3.3	0.08	0.03
							43.45	1.00	0.39

We have decided to give 1.5 to the emergency and contacting devices because we have thought are the most critical attributes. We can possibly have very critical working conditions and our workers also have particular disabilities. For these reason we have prioritized this object.

For the same reason we have given a high weight also to first aid kit. Concerning with the jobs people have to do there we have given also 1 point to guard protection while in operation.

To the last 3 we have given less weight because even if they are very important in our design they are not as critical as the first 3 attributes.

Table 7: Analytic Hierarchy Process (Space use)

	Space Utilization (0.26)			**Total**	**Relative Weight**	**Absolute Weight**
Space Utilization	2.1	2.2	2.3			
2.1	1.00	1.50	0.57	3.07	0.30	0.08
2.2	0.67	1.00	0.44	2.11	0.21	0.05
2.3	1.75	2.25	1.00	4.00	0.49	0.13
				10.18	0.48	0.26

Here the first thing we have prioritized is the easy access with a weight of 1.75. This because for us, especially with people with paraplegia, it's really important to guarantee a fast escape from the workstation in case of emergency to any kind of worker. Also the workstation must be suitable for anyone.

Then, considering the different kinds of disabilities we have focused on working conditions and possibilities and from here the weight of one to a device able to adapt to any worker.

The last is ergonomics because it's important to improve the comfort of the workstation but not so critical to the first 2 things.

Table 8: Analytic Hierarchy Process (Performance)

	Performance (0.19)				**Total**	**Relative Weight**	**Absolute Weight**
Performance	3.1	3.2	3.3	3.4			
3.1	1.00	1.50	1.00	0.50	4.00	0.23	**0.04**
3.2	0.67	1.00	0.67	0.75	3.09	0.18	**0.03**
3.3	1.00	1.5	1.00	0.50	4.00	0.23	**0.04**
3.4	2.00	1.33	2.00	1.00	6.33	0.36	**0.07**
					17.42	1.00	**0.18**

Since our idea is to put the worker in the middle of our design, we have to take in consideration the performances and relate them to safety, because if something bad happens, it is important that the emergency devices have a good performance so we give them the weight of 2.

Then we have given a weight of 1 to the conveyor because most of the performance are not very related to the machine, but to the workers. It must be adaptable, small and fast and has to guarantee the perfect timing and storage between all the prototyping steps. High efficiency refers to all the mechanical-electrical parts of our workstation and their ability to consume as less energy as possible.

Table 9: Analytic Hierarchy Process (Costs)

	Cost (0.16)		Total	Relative Weight	Absolute Weight
Cost	4.1	4.2			
4.1	1.00	2.00	3.00	0.67	0.11
4.2	0.50	1.00	1.50	0.33	0.05
			4.50	1.00	0.16

Here the decision was easier than in many other cases, because the consumers are interested in cheap products, with high quality. So it is important to have a low maintenance costs because it will eventually lower the prototype cost.

And in the table here below we report a summary of our AHP Pairwise Comparison analysis.

Table 10: Final Results of the Analytic Hierarchy Process

Objectives	Absolute Weight	Relative Weight
1. Safety	**0.39**	**1.00**
1.1 Guard protection while in operation	0.08	0.20
1.2 First aid kit	0.08	0.20
1.3 Emergency contacting device	0.11	0.27
1.4 Safety Plan	0.04	0.11
1.5 Safe environment	0.05	0.14
1.6 Course of first aid	0.03	0.08
2. Space utilization	**0.26**	**1.00**
2.1 Regulated tables and conveyors (reach)	0.08	0.30
2.2 Ergonomics	0.05	0.21
2.3 Easy access	0.13	0.49
3. Performance	**0.18**	**1.00**
3.1 High efficiency	0.04	0.23
3.2 High reliability	0.03	0.18
3.3 Auto feeding conveyor	0.04	0.23
3.4 Emergency stop button	0.07	0.36
4. Cost	**0.16**	**1.00**
4.1 Minimal Cost to customers	0.11	0.67
4.2 Low maintenance cost	0.05	0.33

3.3 Objective Tree Diagram

To make easier the comprehension of our choices, we also have decided to report the results of our analysis as an objective tree diagram obtained from the table of objectives grouped by areas of interest.

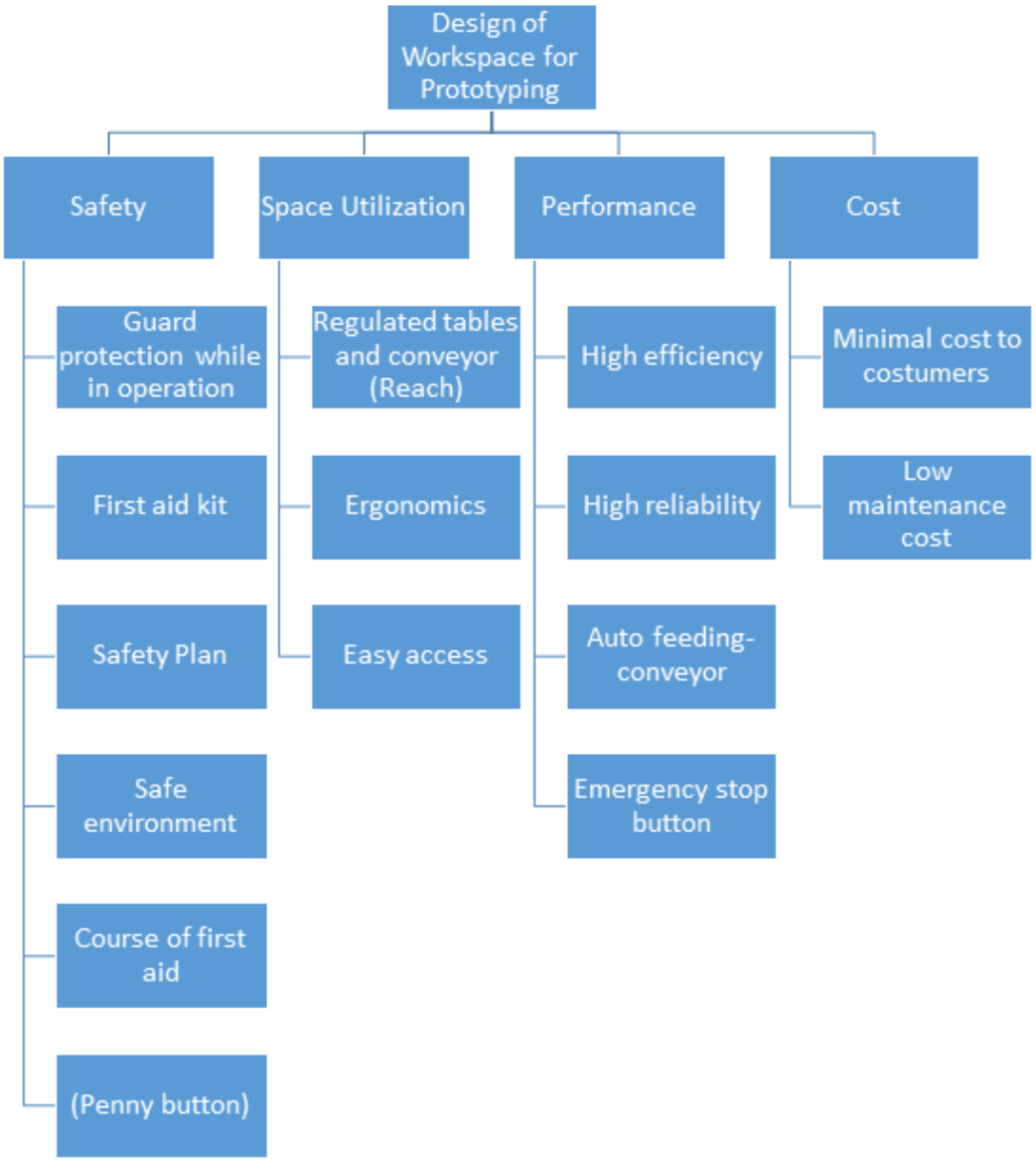


Diagram 1: Objective tree diagram

4. Functional Structure

In this section our goal is to identify the main functions of our workstation and the means we have to achieve them. Thus we have divided our workstation in five critical subsystems each of them with an essential function to be achieved.
In the figure here below we have provided a generic sketch of the main parts of our workstation and all the processes that are happening inside of it.
Doing our analysis we have divided our essential function in some essential sub-functions and for them, we have defined the ways we have to achieve them.

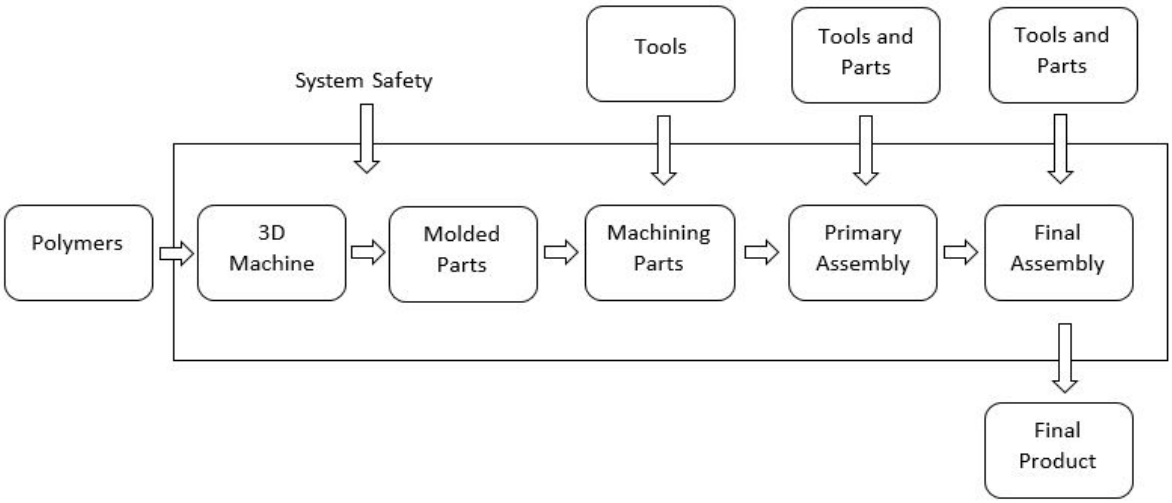


Diagram 2: Open box diagram (Workstation process)

4.1 Results of the work

4.1.1 Essential function and sub-functions for the prototyping machine

The machine we wanted to use is a rapid prototyping machine. With this we want to pass from a CAD 3D model to the physical pieces. For these reasons it must be compatible with all the most recent software of 3D modelling. Other than that it must be able to perform on many different materials, like polymers, and to preform different kind of operations in order to adapt to the different parts we have to produce.

Here below we provide some examples of some possible CNC machines we can use.

Figure 3: Prototyping machine I

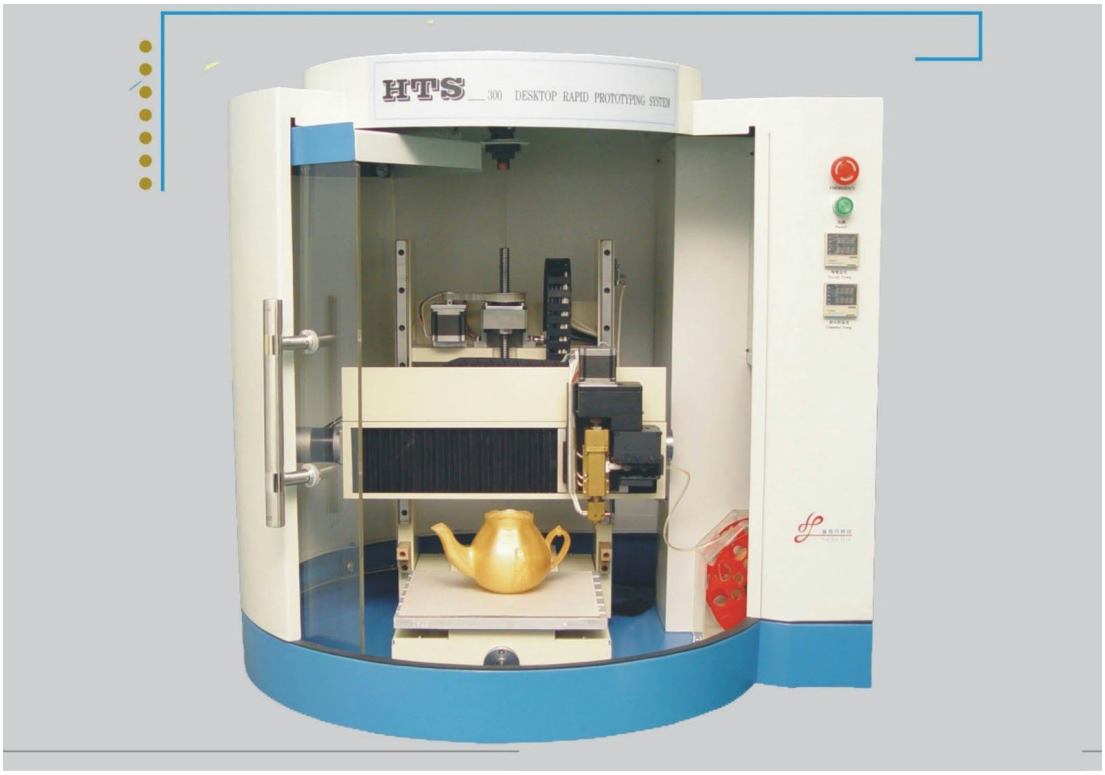


Figure 4: Prototyping machine II

Table 11: Essential function and sub-functions for the prototyping machine

Essential function: Delivery the assembly parts	
Essential Sub-functions	**Means of Achieving the Sub-functions**
Forming Heat treatment Moulding	Computer controlled forming Computer controlled moulding Computer controlled heat treatment Easy feeding CAD-ready

4.1.2 Essential function and sub-functions for the transfer line

The transfer line is a very crucial device for our workstation, in fact it has the responsibility of the delivery of the parts among the workstation but at the same time it must be ergonomic and save as much space as possible. We have adopted it mainly to avoid too much movements of the workers in order to help them and to save space.
Here in the pictures below we have put some examples of some possible transfer lines for the workstation.

Figure 5: Transfer line I

Figure 6: Transfer line II

The mechanism is different among them, the first one works with the use of four little wheels, the second one uses a serial roll system and the last one works with a belt. This examples are just showing that could be used different kind of systems. Below it is shown what the most important characteristic of the transfer belt are.

Figure 7: Transfer line III

Table 12: Essential function and sub-functions for the transfer line

Essential function: Transfer parts	
Essential Sub-functions	**Means of Achieving the Sub-functions**
Avoid movements of the workers Fast manufacturing processes Efficiency	Transfer parts from one station to another automatically Fast and easier communication between the machines and assembly tables

4.1.3 Essential function and sub-functions for the assembly and refining tables

The assembly and refining table is where the final part of the prototyping process happens. Here the parts coming from the CNC machine comes and have to be refined with some tools and then assembled. Also it's really important the ergonomic factor as long as the adaptability of the table to different sizes and positions.
Here below some examples of the table are given:

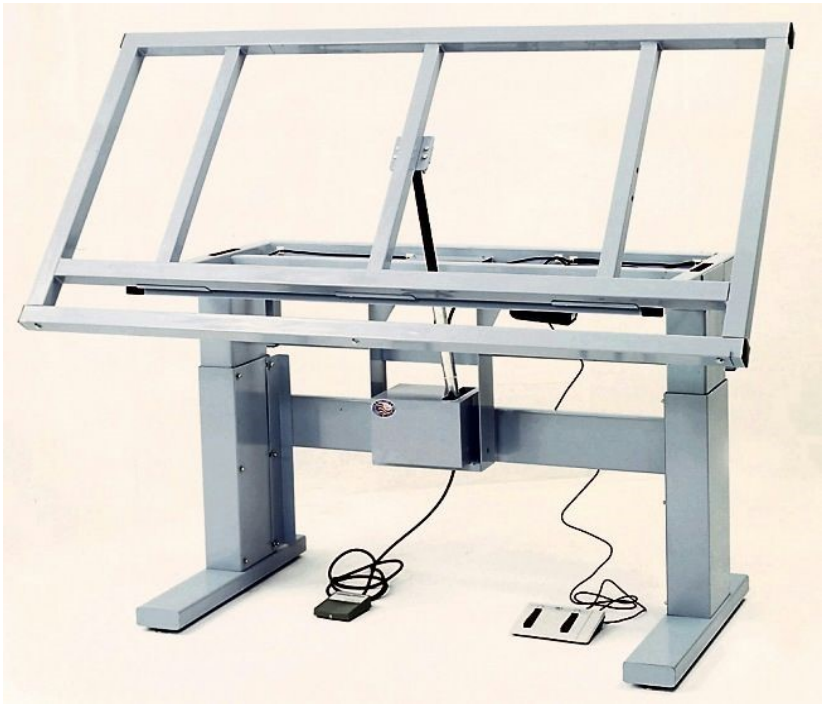


Figure 8: Assembly table I

The workbench or assembly table has to be adjustable in order to provide comfort to the user, it is not easy to use a standard fix table because wheelchairs have a big range of sizes, that is why the easiest way is to consider a mechanical or electromechanical adjustment system. There are some products in the market that we could select, in these pictures, are shown some of them.

Figure 9: Assembly table II

Table 13: Essential function and sub-functions for the assembly and refining tables

Essential function: Support the Assembly	
Essential Sub-functions	**Means of Achieving the Sub-functions**
Provide the parts for completing the door latches Adjust its position for the worker's needs Ergonomic workspaces	By delivering the parts to the worker in the station Adjustable height Adjustable inclination Space for small prototyping tools

4.1.4 Essential function and sub-functions for the Security System

The security system is required to guarantee the safety of the workstation and its workers. Since we are refining parts at high temperature and pressure is necessary a system that can immediately in case of emergency stop the whole workstation. Also is really important to have a recirculation of air to guarantee fresh and sanity of air. Then it's also important to have a communication system and an emergency plan in case of a healthy problem of one of the workers.

4.2 Workstation Needs Chart

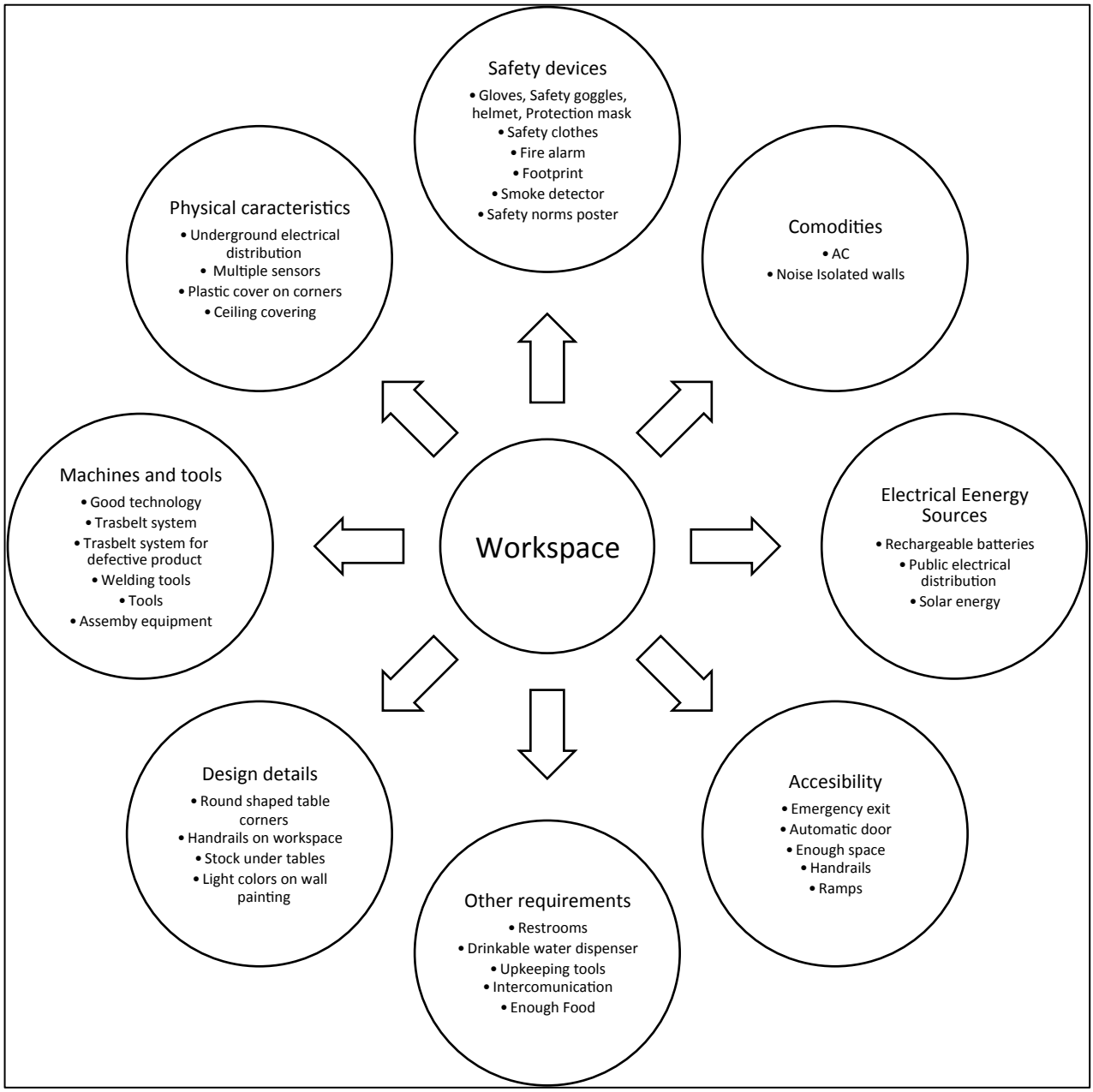


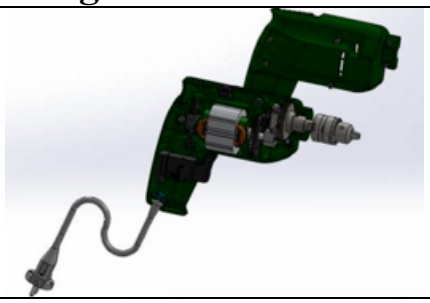
Diagram 3: Relationship between customer needs

This is a diagram of the most representative ideas and shows the relationship between the requirements and the group of the customer needs where they belong. This diagram was made in order to serve as a base on the construction of the morphological chart. To construct this diagram it was used a brainstorming method.

4.3 Tools Diagram

This table shows the principle hand tools that have been considered on the prototyping process, it has also been decided to do a different table for the other parts of the workstation because they don´t have the same requirements of space, energy needs and ergonomic needs. Also has been written a description of the equipment, and a representative picture of the device.

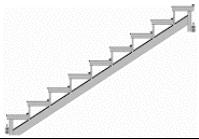
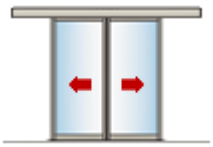
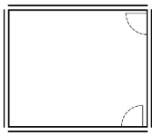
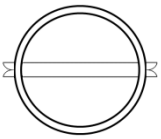
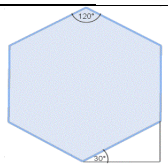
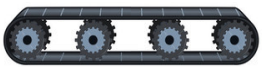
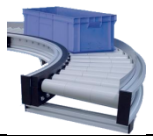
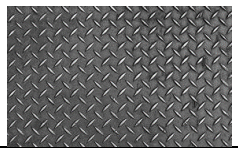
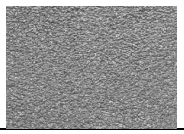
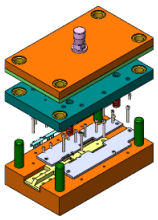
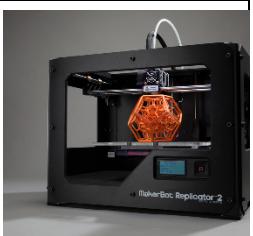
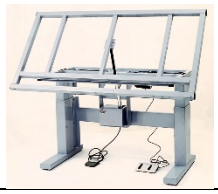
Table 14: Hand-tools table with description

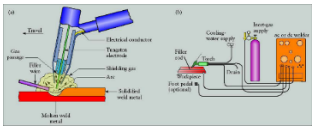
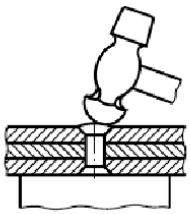
Tool	Image	Description
Drill		It's needed to drill some parts of the piece that the 3D printer can't do
Clamps		used to reduce the force that may be needed, or just to permit working with one arm
Pliers		Used to help grabing some parts of the piece more difficult to reach. Or only to grab the piece, making it easier to maneuver.
Screwdriver		Used to turning the screws.
Wrench		Used to grab, or to help turning the screws.
Machining Tool		Needed to machine and perfect, do the final touch, to smaller and more dificult parts of the component to reach.

Small Sanding Machine		Needed to machine and perfect, to do the final touch.

4.4 Morphological Chart

Table 15: Morphological diagram

	Design 1	Design 2	Design 3	Design 4
Entry				
Doors				
Design of workspace				
Conveyor				
Anti-slip floor				
Smoke detector				
Prototyping machine				
Tables				

Chairs				
Signals				
Communication system				
Air extractor				
Lights				
Link Processes				

The morphological chart shows the different designs that have been selected as an option for solving the customer needs. The decisions were made based on previous experiences on workspace distribution and tools characteristics, it has been considered just four designs, because they are the most representative ones based on shape, functionality and development. We will also decide between these designs by doing a weighted analysis on the next chapter of this report.

4.5 Weight Decision Table

Table 16: General Weight Decision table

Selection Criteria	Weight	Concept							
		Design I		Design II		Design III		Design IV	
		Rate	Weighted Score	Rate	Weighted Score	Rate	Weighted Score	Rate	Weighted Score
Entry	9	2	18	4	36	5	45	3	27
Doors	6	5	30	3	18	1	6	2	12
Design of workspace	10	4	40	5	50	1	10	2	20
Conveyor	6	1	6	2	12	3	18	5	30
Anti-slip floor	8	5	40	3	24	1	8	4	32
Smoke detector	4	2	8	3	12	4	16	1	4
Prototyping machine	9	5	45	3	27	1	9	3	27
Tables	9	5	45	1	9	3	27	4	36
Chairs	7	5	35	3	21	2	14	1	7
Signals	4	3	12	4	16	1	4	1	4
Communication system	10	1	10	5	50	4	40	1	10
Air extractor	7	4	28	3	21	2	14	1	7
Lights	4	4	16	4	16	4	16	5	20
Joint Processes	7	2	14	4	28	1	14	5	35
Total score	100	/	347	/	340	/	241	/	271

Scoring scale:
10-High
5-Medium
1-Low

With this table we find that design one and two shows better results compared to the others available leaving us two possible options.

4.6 Product model table

Table 17: Specific model table

Object	Model	Web page of the product for further details
Prototyping Machine	Comac HT-300	http://italian.alibaba.com/product-gs/rapid-prototyping-machine-206521455.html
Conveyor	Конвейер с пластинчатой цепью	http://wsconveyer.ru/conveyer-s-plastinchatoy-tsepyu.html
Adjustable table	GSA Service Pro-Line Model EWH 7236	http://www.gsaservice.com/pro-line_cable_wire_harness_assembly_station.htm
Smoke detector	Détecteur de fumée BR 102 Brennenstuhl	http://www.habitatetdecouvertes.com/detecteur-fumee-maison/15-detecteurs-de-fumee-br-102-brennenstuhl.html
Adjustable height Chair	SSLB-2	http://varshapillai.trustpass.alibaba.com/product/50011657170-230155985/stainless_steel_adjustable_lab_chair.html
Light	Hallenleuchte 250 Watt	https://www.led-haus.ch/de/led-hallenbeleuchtung/hallenleuchte-250-watt
Air extractor	Pimacon GRELHA 160X160MM C/ CAIXA S/ REGISTO ENTRADA 100MM	http://www.pimacon.com/index.php?pagina=detalhe&ref=0409100802401
Anti-slip Floor	FA1-Mould 1	http://www.alibaba.com/product-detail/Black-Round-Stud-Rubber-Mat-Round_1605117899.html
Communication system	Intercomunicador Intercom M.2005	http://www.bash.cl/index.php/seguridad/ficha/slug/intercomunicador-intercom-m2005
Signals	Opalux OP-296	http://opalux.com.pe/shopexd6cae.asp?id=1546&bc=no

5. Two and three Dimensions Model

To better understand the layout of the workstation, we made a 2D and then a model of it, taking in account the needs of the workers and their safety.

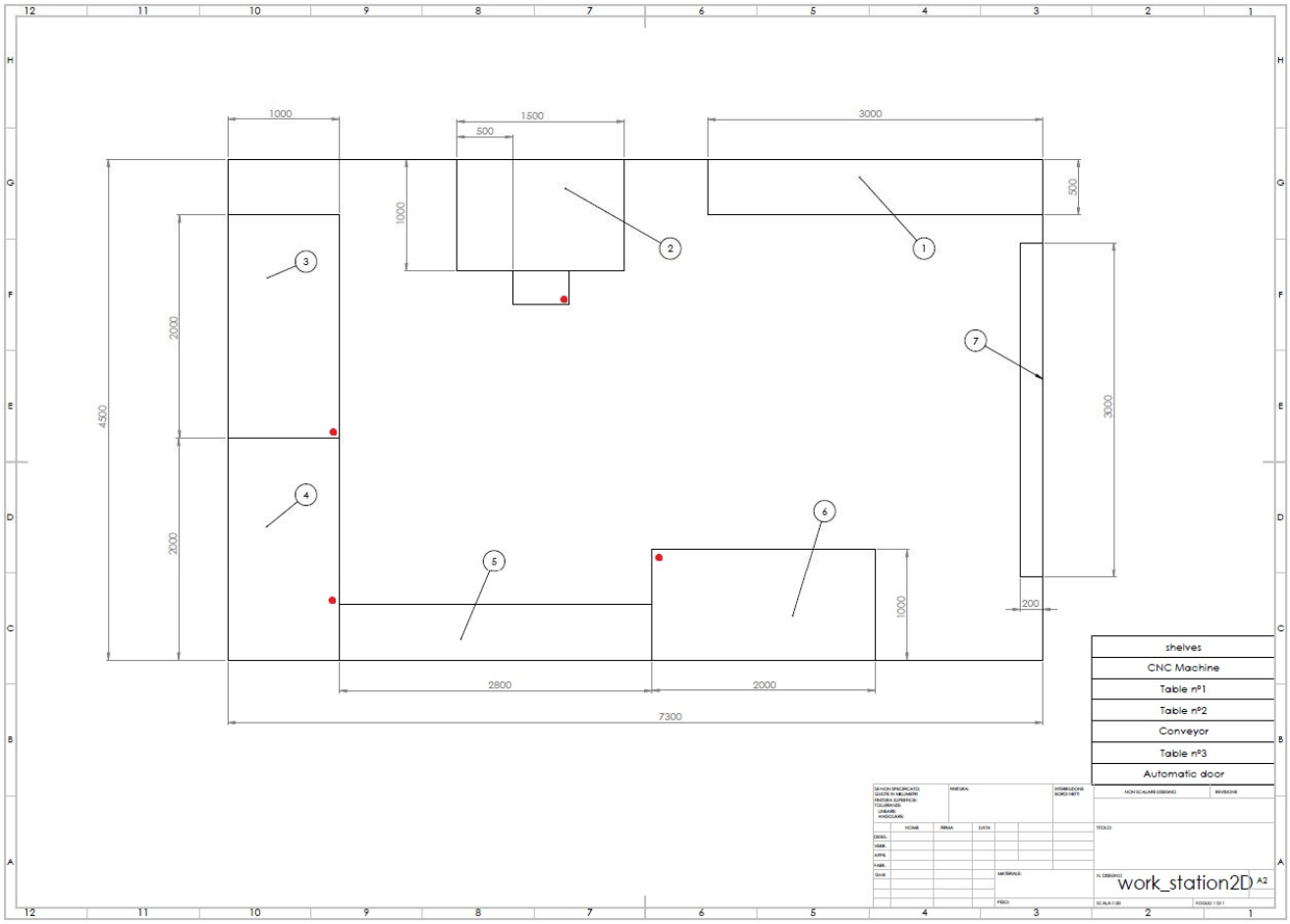


Figure 10: Space distribution 2D model

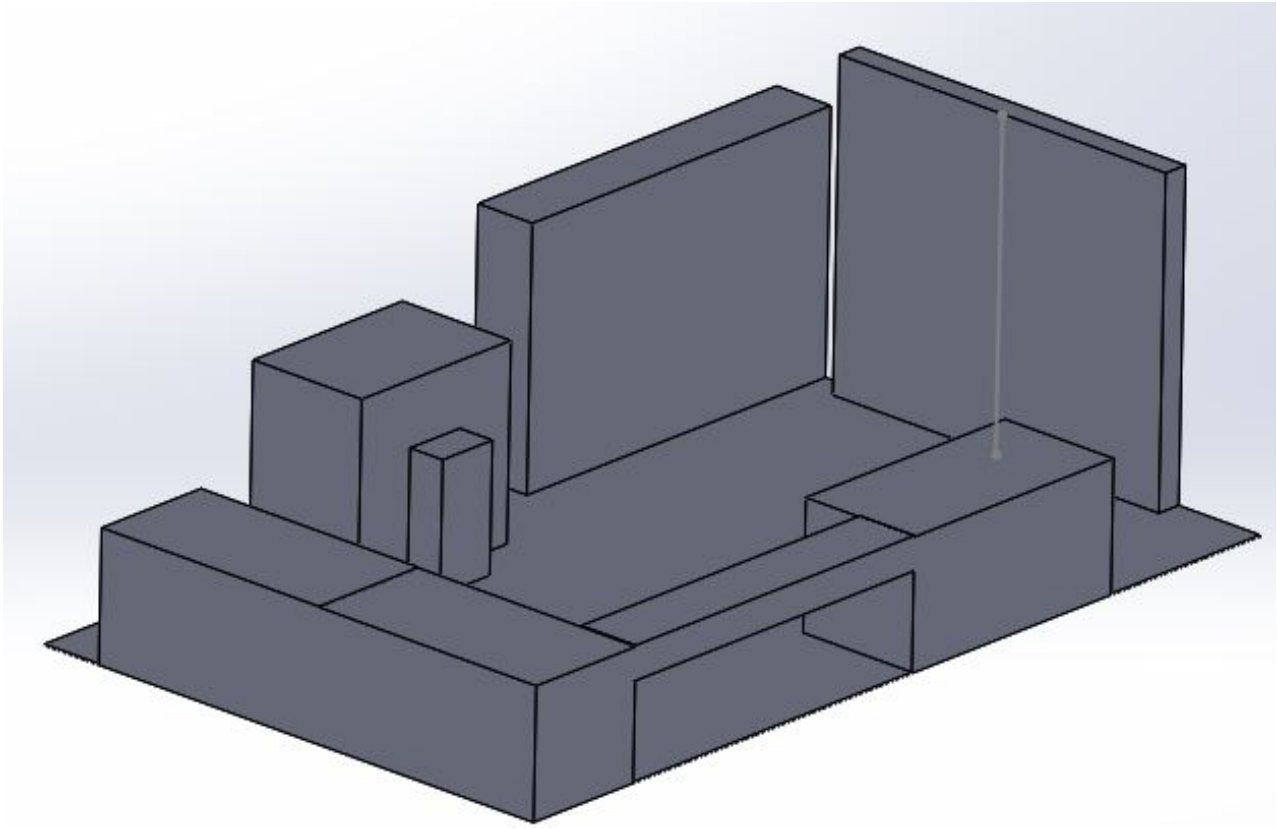


Figure 11: Space distribution 3D model

The workstation has three tables equipped with tools needed for each job and a CNC machine, the first table is the superficial treatment table, where it is used sandpaper and other tools to improve the final prototype, the second is used to join the small parts that are needed, like the wire, and the third table it's were we join the two parts of the model and were we do the final assessment, to check if it has any problem. The CNC machine does almost all of the prototype, because the parts are symmetric, but some of them as to be joint it the tables and not by the machine.

6. Conclusions

Since it is the end part of this design process it's time to draw some conclusions.
During this process many technics were adopted, like brainstorming sessions, AHP Pairwise comparison, CAD models, charts, and many other methods. All of these helped better understanding the problem and the sub-problems. These also helped making some decisions that, in an intercultural group with different backgrounds, sometimes was not an easy task.

The internet was a very good tool to help getting some ideas and finding some solutions. This work is particularly focused on display of ideas thru the use of images similar to the objects we wanted to represent or use.

At the beginning of this problem it has been found many ways to proceed, but we all agreed that in a workstation, more than machines, or final products, the thing that really matter is the worker. So it is necessary to provide a safety and excellent place to work, for them. So efforts have been made to let any sub-part of our workstation be usable by any worker with any kind of disability and partially, this task has been accomplished.
At the end, the result of this project is the complete workstation, mostly characterized in any particular part but at the same time customizable, in case of particular needs of the costumer, or further improvements in the following years with the advance of future technologies.

Overall the task has been accomplished and a final product has been provided. Starting with many different ideas, the result that has been obtained is a mixture and a redefinition of all of them into what it is probably one of the best design of this kind of workstation.

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