Politecnico di Milano

Scuola di Ingegneria

Corso di Studio in Ingegneria Gestionale

PLANNING THE LAYOUT FOR THE NEW PROJECTS ROOM OF THE DEPARTMENT OF PRODUCTION ENGINEERING AT THE UNIVERSITY OF SÃO PAULO

Dottoressa Cristina Rossi Lamastra

Danilo Massato Nomura

764894

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ESTRATTO

L'obiettivo di questo lavoro è fare il progetto del layout per la nuova Aula di Progetti della Scuola Politecnica dell'Università di San Paolo, uno spazio pensato per gli studenti, dove si potrà sviluppare una serie di progetti, con una maggiore attenzione ai progetti di sviluppo di prodotti.

Ci saranno molte risorse disponibili all'interno della nuova Aula di Progetti, che vanno dalle risorse di base, come mobili, lavagne e televisori, alle risorse più specifiche, come ad esempio i computer con una varietà di software, apparecchiature di analisi ergonomica, apparecchiature per il trattamento delle immagini e stampanti 3D.

Principalmente due discipline del corso di Ingegneria Industriale saranno utilizzate durante lo sviluppo di questo progetto: progettazione di layout ed ergonomia.

La conoscenza di ergonomia è utilizzata principalmente durante l'esecuzione di interviste, l'analisi di situazioni di riferimento e l'analisi delle situazioni di azione caratteristica. Informazioni che saranno ulteriormente utilizzate come base per gli strumenti di pianificazione di layout viene raccolta durante l'analisi ergonomica.

Tre alternative di layout vengono presentate, per le quale i modelli 3D sono progettate. Con i modelli 3D è possibile simulare e visualizzare gli elementi della nuova Aula di Progetti al suo interno, che permette di fare una scelta migliore della soluzione.

ABSTRACT

The goal of this paper is planning the layout for the new Project Room, a space designed for students, where they may develop a variety of projects, with greater focus on product development projects.

There will be many available resources inside the new Project Room, ranging from basic resources, such as furniture, whiteboards and TVs, to more specific resources, such as computers with a variety of software, ergonomic analysis equipment, image processing equipment and 3D printers.

Mainly two disciplines from the Industrial Engineering course will be used during the development of this project: layout planning and ergonomics.

Knowledge from ergonomics is mainly used during the execution of interviews, the analysis of reference situations and the analysis of characteristic action situations. Information that will further be used as the base for the layout planning tools is collected during the ergonomics analyses.

Three alternatives of layout are presented, for which 3D models are build. With the 3D models it is possible to simulate and visualize the elements of the new Project Room inside it, making it possible to make a better choice of solution.

Keywords: Ergonomics, Layout

1 INTRODUCTION

InovaLab@POLI is a multidisciplinary laboratory which provides resources for engineering projects (software, hardware, 3D printers, mechanics and electronics workshops) located in the Department of Production Engineering of the University of São Paulo, with free access for all undergraduate students of the University of São Paulo. (InovaLab@POLI 2013)

InovaLab@POLI aims to stimulate the use of resources for innovation by undergraduate students, motivate students to continue improving their technical training and strengthen the training of complementary skills such as the ability to work in teams, knowledge of the market and customer service and creativity to find solutions, communication skills and entrepreneurial mindset. As of now, around BRL1 million has been invested in the laboratory.

Among several initiatives related to InovaLab@POLI, this work will be developed in the new Project Room, which will be located in the new building of the Department of Production Engineering of POLI[1] (PRO). The Project Room is an environment designed to allow students to work on their projects with the support of advanced features and an environment that encourages collaborative work in teams, exchange of experiences and knowledge sharing. (InovaLab@POLI 2013)

In the new Project Room, students will be offered space, equipment, and various software tools for the development of engineering projects, especially projects of product development.

Although the use of the new Project Room is not restricted to classes, with free use for all the University of São Paulo (USP), even for personal projects, there is a large number of professors from the Department of Production Engineering that have showed interest in developing projects for their respective disciplines that can take advantage of the laboratory.

[1] POLI is the acronym for the Engineering School in the University of São Paulo

Table 1-Disciplines which have showed interest in using the new Project Room

Code	**Discipline**
PRO2715	Project of the Product and of the Process
PRO2713	Quality Management of Products and Services
PRO2420	Factory Project
PRO2313	Ergonomics, Health and Labor Safety
PRO2421	Techniques of Industrial Operations Management
PRO2801	Project Management
PRO2814	Production and Sustainability
PRO2804	Project, Process and Innovation Management
PRO2614	Marketing Principles for Production Engineering
PRO2718	Product Project and Engineering II
PRO2315	Ergonomics I
PRO2317	Ergonomics II
PRO2719	Materials and Production Process III
PRO2720	Product Project and Engineering III
PRO2721	Materials and Production Process IV
PRO2318	Project Management in Design

Source: Professor Eduardo de Senzi Zancul

Currently the Project Room is located in the current building of the Department of Production Engineering, on the first floor; however, there is a Project for the construction of a new building for the department, and in this new building, there is a room specially reserved for the Project Room.

1.1 Goal

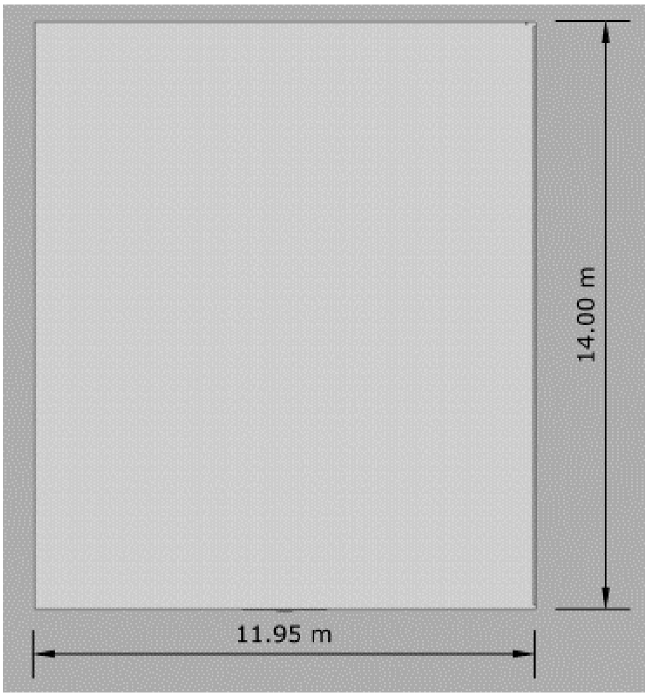
The goal of this work is to plan the layout of the new Project Room which will be located in the new building of the Department of Production Engineering.

Through this work, we hope to design a layout that meets the objectives of the Project Room and InovaLab@POLI, of providing the necessary elements for the development of engineering projects, of promoting teamwork, knowledge sharing, of exchanging experiences and of developing communication, entrepreneurship and creativity of its members.

1.2 Problem definition

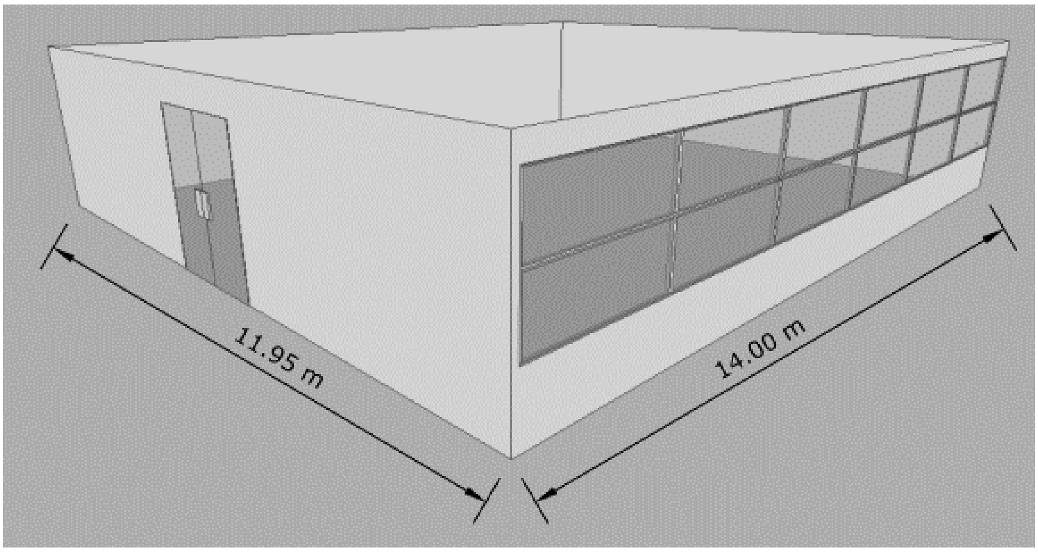
In the new building of the Department of Production Engineering, the Project Room has a space reserved specially to it in the first floor. In the new building, a room of dimensions (11,95 x 14,00) m, with a total area of 167,30 m^2 will be made available.

Figure 1-Top view of the new Project Room



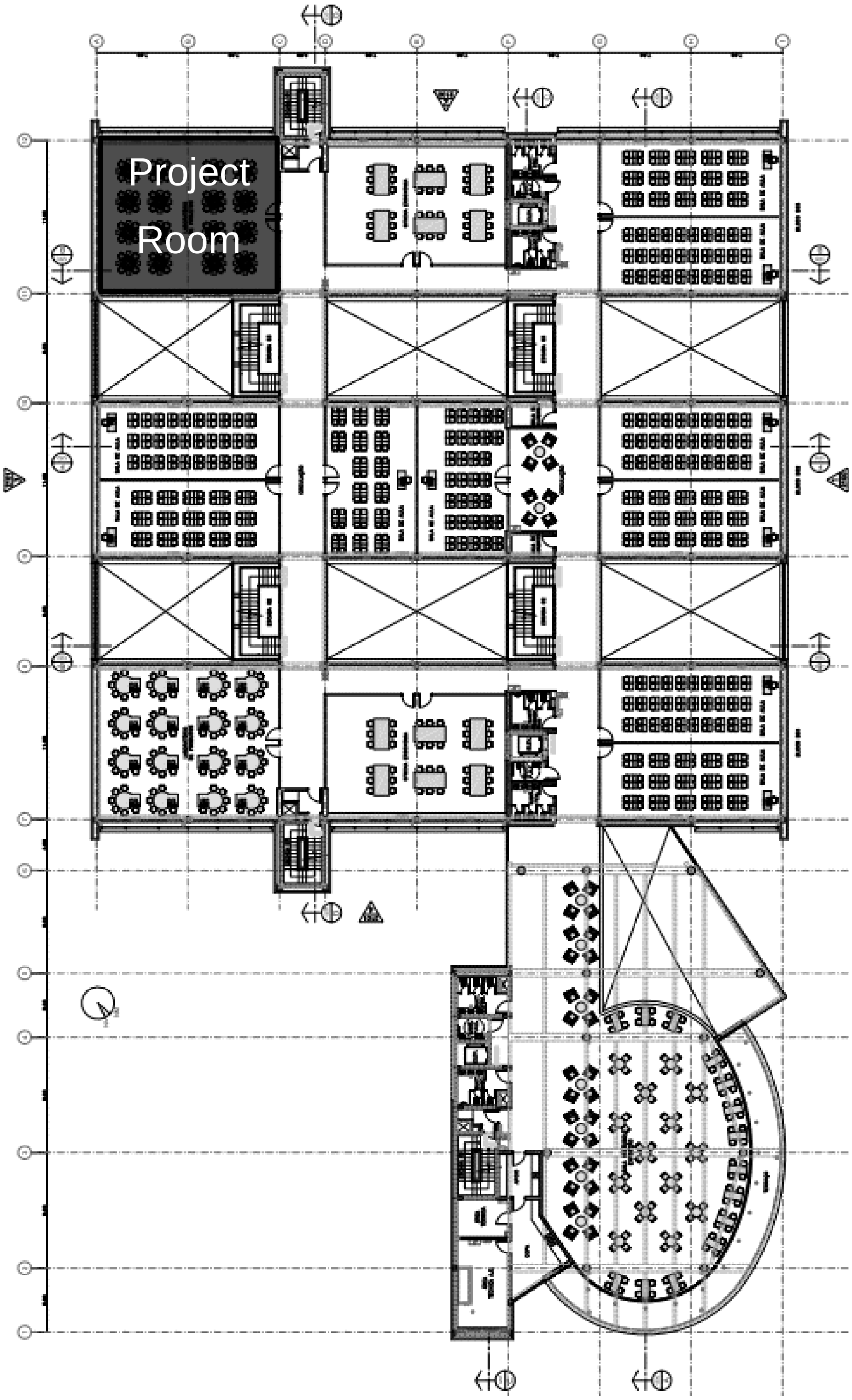
Source: Author

Figure 2-Isometric view of the new Project Room



Source: Author

Figure 3-Location of the new Project Room on the blueprint of the new building of the Department of Production Engineering



Source: Blueprint of the new building of the Department of Production Engineering

As for the elements that will make up the new Project Room, those which are directly linked to the development of projects within the room, such as ergonomic analysis equipment, image processing equipment, software and 3D printers are already defined in the specifications and quantity.

As for computers, its technical specifications are already defined, but their quantity is not defined yet. With regard to furniture, there is still no definition.

The scope of this project is to define:

1. The layout Project of the new Project Room, with views and a 3D model with its elements inside it.
2. Definition of the necessary amount of computers.
3. Definition of the specifications and of the necessary amount of furniture.

1.3 Methodology

The methodology used in this project seeks to integrate knowledge from two disciplines of the production engineering course: layout planning and ergonomics.

Initially, ergonomics' methodology and analysis tools will be used to conduct interviews and to study and to analyze reference situations to assist in the design of the layout of the new Project Room. Interviews with various actors, studies of reference situations, observations and analysis of characteristic situation actions will be taken.

From the collected data, it is possible to use the methodology and tools of layout planning to design the layout of the new Project Room, analysis of the elements of the physical arrangement will be held to select the type of procedure, type of physical arrangement, interrelation chart and diagram, and finally to propose alternatives for the final layout.

Throughout the design of the layout, it is possible to use ergonomics again to define details linked to the comfort and the safety of users, mainly due to the results of interviews and analysis of reference situations, which may also help in the design of use and safety patterns of the new Project Room.

2 BIBLIOGRAPHIC REVIEW

Through bibliographic review, it will be possible to extract tools and methodologies of interest to the development of this project in the fields of layout planning and ergonomics.

2.1 Layout planning

Physical arrangement planning, also called layout, deals with the physical arrangement of transformation resources. The way of how transformation resources are arranged directly affects the way of how processed resources (materials, information and clients) flow through the operation. (Slack, Johnston, & Chambers, 2002)

Any organization, at some moment, must decide its physical arrangement. Whether a food industry, which must decide how buildings, machinery and people will be arranged; whether a law firm, which must organize tables, chairs in a rented space; the way of how resources are arranged in the organization may seriously impact the results achieved.

The importance of physical arrangement varies from organization to organization, mainly depending on the type of product or service provided and the volume of their outputs.

2.1.1 The importance of physical arrangement

For Muther (1978), the physical arrangement has relevant importance in avoiding losses in organizations. The installations of buildings, machineries and equipment without planning and with subsequent rearrangements to find a satisfactory layout means losses with equipment idleness, work stoppage, demolition of buildings, walls and structures.

According to Slack, Johnston, Chambers (2002), changing physical arrangement is a difficult an lengthy activity because of physical dimensions of transformation resources moved; the physical rearrangement of an existing operation may interrupt its proper functioning, leading to a decrease of client satisfaction or losses in production; if the physical rearrangement is wrong, it may lead to longer or confusing flow paths, material stock and customer queues throughout the operation, inconveniences for the clients, long-lasting processes, inflexible operations, unpredictable flows and high costs.

Besides the negative aspects which a badly skewed allocation of resources may bring to the organization, it is clear that a well-planned physical arrangement which considers relevant characteristics of the organization (such as production's mix and volume, the production process stages, flows of processed resources, etc.) may bring consistent returns in terms of efficiency and effectiveness to the organization.

Analyzing Muther (1978) and Slack, Johnston, Chambers (2002), it is possible to infer that the decision regarding physical arrangement includes some long-term choices, such as the positioning of buildings and walls, that is why the choice of a bad physical arrangement may lead to negative consequences to the organization. So, even if it seems to be a simple decision, it must be always well justified before put into practice.

In an office, it may be used the same principles and procedures of traditional physical arrangement planning, however, for offices planning, it is necessary especial attention to some elements. The main differences between the physical arrangement planning of an office and the traditional physical arrangement planning are (Lee, Amundsen, Nelson, & Tuttle, 1997):

- Affinities depend more on communications and on people movement instead of materials movement
- Restrictions to the physical arrangement normally have a more psychological or organizational character than the spatial character
- Internal politics and individuals' personalities have more influence

2.1.2 Objective of physical arrangement planning

The physical arrangement planning has as objective to organize work areas and equipment in the most economical way of functioning, but also considering safety and the satisfaction of employees. This general objective can be achieved following six principles of physical arrangement (Muther, Practical Plant Layout, 1955):

1. **Principle of total integration**: the physical arrangement is better with integration of workers, materials, equipment, activities of support and any other relevant considerations, in such a way that results in the best resource employment.
2. **Principle of minimum moved distance**: everything else remaining equal, the physical arrangement is better when it allows materials to be moved through the minimum distance between operations.
3. **Principle of flow**: everything else remaining equal, the physical arrangement is better if one organizes the work area for each operation or process in the same order or sequence in which the materials are processed.
4. **Principle of cubic space**: it is possible to have savings through the effective use of all available space, both horizontal and vertical.
5. **Principle of satisfaction and safety**: everything else remaining equal, the physical arrangement is better if planned in a way which provides safe and satisfactory conditions for workers.
6. **Principle of flexibility**: everything else remaining equal, the physical arrangement is better if it can be adjusted and rearranged at the lowest cost and inconvenience.

2.1.3 Characteristics of a good physical arrangement

It is important to define objectives from the physical arrangement project detailing. Although the objectives depend on specific circumstances of the organization, according to Slack, Johnston, Chambers (2002), the relevant objectives for all operations are:

- **Inherent safety**: all the processes that may put operations in jeopardy must not be accessible to non-authorized people.
- **Flow extension**: the flow of materials, information or client must be canalized by the physical arrangement, in a way that accomplishes operations' objectives.

- **Flow directness**: all the flow of clients and materials must be signalized in a clear and direct way for clients and workers.
- **Workers comfort**: workers must be allocated in places far from unpleasant and noisy parts of operations. The workplace must be ventilates, illuminated and, if possible, pleasant.
- **Managerial coordination:** supervision and coordination must be facilitated by workers location and communication devices.
- **Access**: all the machinery, equipment, facilities must be accessible to allow adequate cleaning and maintenance.
- **Use of space**: the physical arrangement must allow adequate use of available space in operations (including cubic and floor space).
- **Long-term flexibility**: the physical arrangement must be changed as the necessities of operation vary. A good arrangement is planned keeping in mind potential future needs.

2.1.4 Physical arrangement elements

There are five basic elements on which a physical arrangement is planned (Muther, Planejamento do layout: sistema SLP, 1978):

- **(P) Product**: what is produced or done.
- **(Q) Quantity**: how many of each item must be done.
- **(R) Routing**: the process, its operations, equipment and sequence.
- **(S) Support services:** resources, activities or auxiliary functions which must supply the area in discussion and will give it conditions to function effectively.
- **(T) Timing/Transport:** when, for how long, how often and with what deadline.

Product (P) and quantity (Q) are elements which define the main characteristics of physical arrangement, basic decisions regarding the physical arrangements of a given business must take into consideration the range of products and the quantity of each product to be made.

About the routing (R), it explains how items are produced, what are the transformations needed and what the sequence in which these transformations must occur is. The routing can be defined through lists of operation and equipment, proceeding charts and flow charts.

Support services (S) are those that are not directly linked to items production, however, without which the organizations would not function well. The support services include maintenance, catering, first-aid attendance, shipping and receiving sectors, bureaus and storage areas.

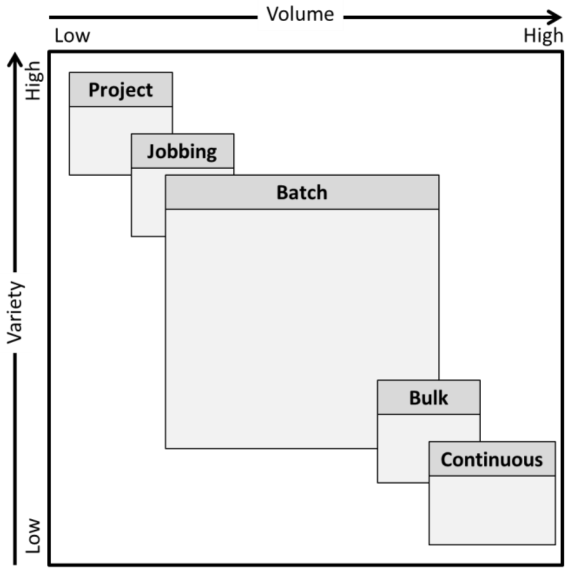
Timing/Transport (T) deals with issues such as when to produce, when the physical arrangement project will begin and what is the processing time of each machinery. When organizations seek optimize the use of their resources, the element time become the main aspect in the physical arrangement planning.

2.1.5 Kinds of processes

The position of an organization regarding volume and mix of products and services has implications in many aspects of physical arrangement planning.

For Slack, Johnston, Chambers (2002), in manufacture, processes can be divided in the so-called kinds of process in accordance with volume and mix produced. In an increasing order of volume and decreasing order of mix are:

Figure 4-Kinds of process



Source: Adapted from Slack, Johnston, & Chambers (2002)

- **Project process**: discrete products, commonly customized and with lengthy production time. There is flexibility in activities done during production. Its essence is that each product has a start and end clearly defined. The transformative resources are normally organizes in a specific manner for each product. Example: building ships, film making, build tunnels, produce turbo generators, drilling oil and gas wells, installation of a computer system.
- **Jobbing process:** it is someway similar to the project process, but instead of having resources more or less dedicated to each product, the products must share resources with each other. Although all products require the same kind of attention, they will differ from each other by exact needs. It produces more and usually smaller items than the project process. Examples: toolmakers masters of specialized tools, furniture restorers, tailors who work on demand, graphics services providers.
- **Batch process**: as the name indicates, when more than one product is produced. The batch size can be small, two or three products, resembling the jobbing process, especially if each batch is an entirely new product; or the batch size can be large, and if the products are familiar with the operation the process may be relatively repeatable. For this reason, the batch process may be based on a wide range of levels of volume and mix. Examples: manufacturing of machine tools, manufacturing most part of pieces assembled in mass, clothes manufacturing.
- **Bulk process**: repetitive and highly predictable. It produces goods of high volume and a relatively narrow mix in terms of the fundamental aspects of the product design. The different variants of the goods do not affect the basic production process. Examples: car manufactures, manufacturers of durable goods, bottling beer, CDs’ production.
- **Continuous process**: it lays one step beyond the bulk process due to the fact that it operates with higher volumes and lower mix. It usually operates for long periods of time. Sometimes, it is literally continuous, since the product is inseparable and the flow is continuous. It is often linked to inflexible and capital intensive technologies with highly predictable flow. Examples: petrochemical refineries, power plants, steelmakers and paper production plants.

2.1.6 Types of physical arrangement

After selecting the kind of process, it is possible to select the kind of physical arrangement that best suits it and the organization's goals.

The choice of physical arrangement does not precisely define the exact position of each element of the operation, although according to the general rule the resources will be arranged in relations to each other, (Slack, Johnston, & Chambers, 2002)

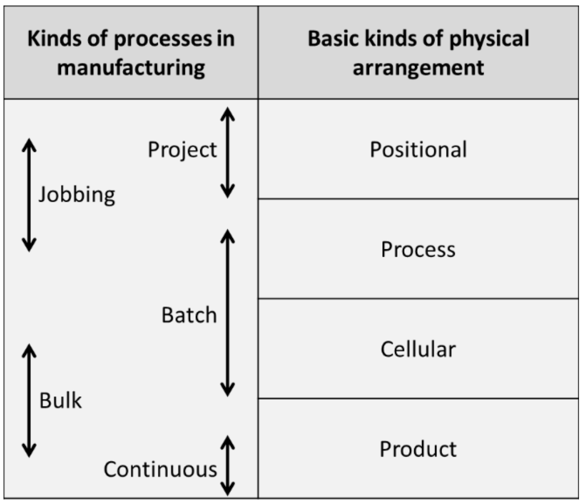
According to Slack, Johnston, Chambers (2002), the basic kinds of physical arrangement are:

- **Positional or fixed position physical arrangement**: the processed resources do not move themselves between transformation resources. The material that suffers processing is stationary, while equipment, machinery, facilities and people move when it is necessary. One selects this physical arrangement when the processed resource has very large dimensions, making it difficult to displace, or it is in a position where it cannot be moved. Examples: highway construction, heart surgery, shipyard, maintenance of large computers.
- **Physical arrangement by process**: similar processes, or with similar needs, are put together. The justification of the decision for this physical arrangement can be due to the operational convenience to keep them together, or due to the benefit that it brings for the use of resources. The processed resource is displaced from process to process according to their needs, there are different itineraries enabling the operation. Examples: hospital, machining parts for aircraft engines.
- **Cellular manufacturing layout**: resources processed are preselected to move in a specific part of the operation (cell), in which all the transformation resources necessary to meet processing needs are arranged. The cell itself can organize itself according to a physical arrangement by process or by product. Once processed by the cell, the transformed resource may or not move to another cell. The cellular manufacturing layout is an attempt to bring order to the existing flow in the complex physical arrangement by process.

Examples: maternity hospital, manufacturing companies of computer components.

- **Physical arrangement by product, in flow, inline**: it locates productive transformation resources entirely on the best convenience of the resource that is being transformed, following a predefined itinerary in which the sequence of required activities matches the sequence in which the processes were organized physically. The flow is very clear and predictable, which makes it easy to control. What makes the use of the physical arrangement by product possible is the uniformity of resource requirements processed. Examples: car assembly, mass vaccination program, self-service restaurant.

Figure 5-Relations between kinds of process and basic kinds of physical arrangements



Source: Adapted from Slack, Johnston, & Chambers (2002)

2.1.7 Physical arrangement selection

The decision by the kind of physical arrangement is first defined by the characteristics of volume and mix of the operation. Still, more than one basic kind of physical arrangement can meet the necessities of the same kind of process. For this reason, after a previous analysis of the possible options of physical arrangement for the operation, it must be analyzed the advantages and disadvantages of each option for the operation. (Slack, Johnston, & Chambers, 2002)

Table 2- Advantages and disadvantages of each kind of physical arrangement

	Advantages	Disadvantages
Positional	• Very high flexibility of product and mix • Product or customer not moved or disturbed • High variety of tasks for workforce	• Very high unit costs • Space or activities programming can be complex • It can mean a lot of equipment moving and workforce
Process	• High flexibility of mix and product • Relatively robust in case of interruption of steps • Relatively easy supervision of equipment and facilities	• Low resource utilization • It may have high work in process stock or customers queues • Complex flow can be difficult to control
Cellular	• It provides a good balance between cost and flexibility for operations with relatively high variety • Fast displacement • Work in group can result in better motivation	• It can be expensive to reconfigure the current physical arrangement • It may require additional capacity • It can reduce levels of resource utilization
Product	• Lower unit costs for high volumes • It gives opportunity for specialization of equipment • Convenient displacement of customers and materials	• It may have low flexibility of mix • It is not very robust against interruptions • Work can be repetitive

Source: Adapted from Slack, Johnston, & Chambers (2002)

2.1.8 Inter-relations not based on material flow

In traditional organizations, the physical arrangement planning usually prioritizes the material flow in order to optimize the location of resources, in this case, tools and methodologies, such as material flow analysis, proceeding charts, from-to charts, between others, meet well the necessities of this kind of system. However, in some cases, the flow of materials by itself cannot be considered as the basis of physical arrangement planning. Examples include service-provider organizations in which materials flow does not have importance for the physical arrangement, whether because the materials are moved by tubes or cart loads, whether because moved volumes are small. In those cases it is possible to use a chart of preferred interconnections.

The chart of preferred interconnections is a triangular matrix that represents the proximity grade and the kind of interrelation between a certain area and each other areas. In the cell that holds two areas crossing, one must insert the importance of the relation and the justification of this importance. The objective of this chart is showing which activities should be located nearby and which ones should be put far from each other.

To rate the importance of the relation, it is used the A, E, I, O, U, X scale.

Table 3- A, E, I, O, U scale

Scale	Color	Meaning
A	Red	Absolutely necessary
E	Yellow	Especially important
I	Green	Important
O	Blue	Ordinary closeness
U	White	Unimportant
X	Brown	Undesirable

Source: Adapted from Muther, Planejamento do layout: sistema SLP (1978)

The reasons of importance vary from case to case; it uses a numeric code to ease the insertion of reasons and the visualization of the chart.

Table 4-Code of physical arrangement elements

Code	Element
1	President
2	Mr. Mesquita
3	Engineering area
4	Secretariat
5	Door
6	Central archive
7	Equipment room
8	Copy machine
9	Warehouse
10	Natural light (windows)
11	Telephones

Source: Adapted from Muther, Planejamento do layout: sistema SLP (1978)

Table 5-Chart of preferred interconnection

	Telephones	Natural light (windows)	Warehouse	Copy machine	Equipment room	Central archive	Door	Secretariat	Engineering room	Mr. Mesquita
President	A 2	I 4	U	X 3	U	O 2	I 2	A 1	U	O 1
Mr. Mesquita	E 2	O 4	U	U	O 2	I 2	O 2	I 1	A 5	
Engineering area	E 2	O 4	U	U	E 2,7	I 2	U	U		
Secretariat	A 2	I 4	I 1	I 1	U	E 1	E 6			
Door	U	U	A 7	U	O 7	U				
Central archive	U	O 4	U	U	O 8					
Equipment room	U	U	U	U						
Copy machine	U	U	E							
Warehouse	U	U								
Natural light (windows)	U									

Source: Adapted from Muther, Planejamento do layout: sistema SLP (1978)

Table 6-Quantity of interconnections

Value	Proximity	Quantity
A	Absolutely necessary	5
E	Especially important	6
I	Important	8
O	Ordinary closeness	9
U	Unimportant	26
X	Undesirable	1
Total		55

Source: Adapted from Muther, Planejamento do layout: sistema SLP (1978)

Table 7-Reasons for interconnections

Code	Reason
1	Personal interaction
2	Convenience
3	Noise, disturbance
4	Light
5	Common use of equipment
6	Reception
7	Equipment displacement
8	Similar kind of equipment

Source: Adapted from Muther, Planejamento do layout: sistema SLP (1978)

After elaborating the chart of preferred interconnection, it is possible to generate a diagram that aims to ease the visualization of existing findings in the chart. Each element that must be included in the physical arrangement is represented, as well as the intensity of preferred interconnections among them.

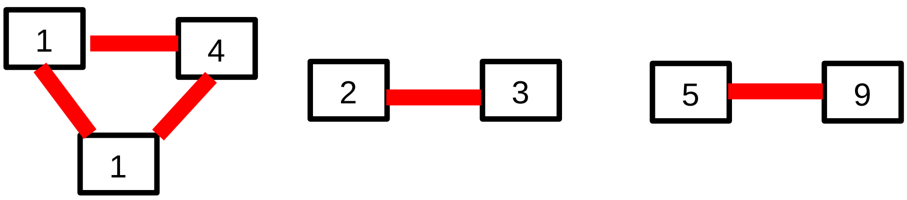
Table 8-Intensities and colors of interconnections

Scale	Color	Type of line	Proximity
A	Red		Absolutely necessary
E	Yellow		Especially important
I	Green		Important
O	Blue		Ordinary closeness
U	White		Unimportant
X	Brown		Undesirable

Source: Adapted from Muther, Planejamento do layout: sistema SLP (1978)

To design the diagram, one initiate by the interconnection of class A, connecting all the elements in a short distance of one another with a line of type A. Throughout the development of the diagram, one must keep in mind that there are innumerous ways of allocation element, that is why, it may be convenient to propose different ways in arrangement while in this stage. Besides, in each stage it is usually necessary to rearrange some elements.

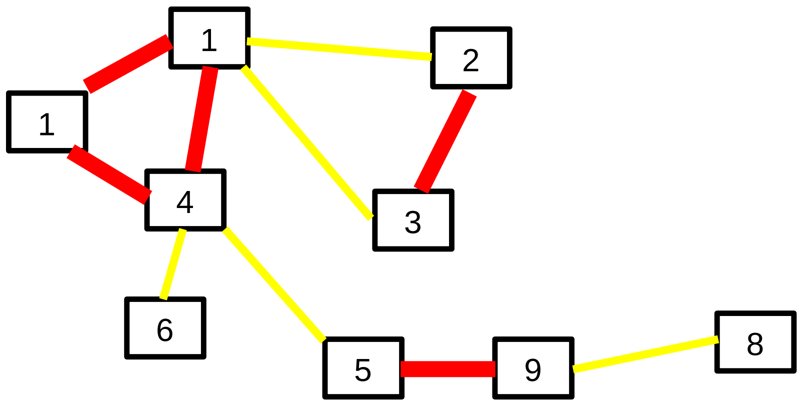
Figure 6-Interconnections of type A



Source: Adapted from Muther, Planejamento do layout: sistema SLP (1978)

After that, one inserts the interconnections of class E, finding a kind of arrangement in which their length is approximately the double of interconnections of class A.

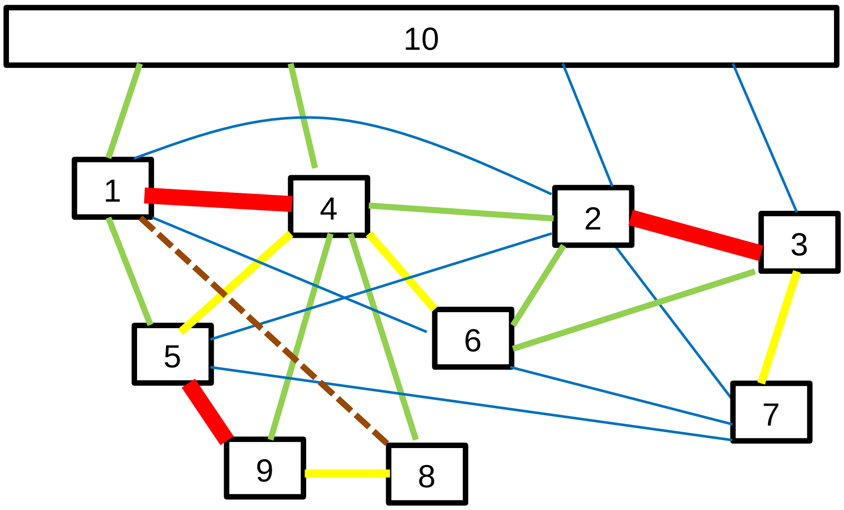
Figure 7-Interconnections of type E



Source: Adapted from Muther, Planejamento do layout: sistema SLP (1978)

Then, successively, interconnections o class I, O and X are included.

Figure 8-Interconnections of types I, O and X



Source: Adapted from Muther, Planejamento do layout: sistema SLP (1978)

While designing the diagram, it is necessary to avoid that connection lines stay unnecessarily matted. For that, one can withdraw some elements and interconnections from the diagram. For instance, the element 11 (telephones) can be easily installed in any other place, so it was not necessary to present it in the last diagram.

When an element remains close to many others, it is possible to represent it deforming its typical symbol, easing visualization, as it was done with element 10 (windows).

If an element is linked to many others, this is an indication that it might be divided or decentralized.

The finished diagram represents the ideal theoretical interconnection of activities, independently of the necessary area for each one.

2.1.9 Detailed physical arrangement project

After the decision for the basic kind of physical arrangement through the analysis of kinds of process and advantages and disadvantages of each basic kind of physical arrangement, it is possible to decide the detailed physical arrangement. The outputs of this stage are (Slack, Johnston, & Chambers, 2002):

- Physical localization of all facilities, equipment, machinery and people that take part of the operation work centers
- The space to be allocated to each work center.
- The tasks that will be done by each work center.

2.2 Ergonomics

According to Guérin (2001), the aim of ergonomics is transforming work.

According to the ABERGO website, in august 2000, the International Association of Ergonomic adopted an official definition of ergonomics following presented:

> *Ergonomics (or Human Factors) is a scientific discipline related to the understanding of interactions among human beings and other elements or systems, and the application of theories, principles, data and methods into projects in order to optimize human well-being and overall performance of the system. Ergonomists contribute to the planning, design and tasks' evaluation, jobs, products, environments, and systems in a way that makes them compatible with people needs, abilities and limitations. (Brazilian Ergonomics Association, 2013)*

Ergonomics aims two goals (Falzon, 2007) (Guérin, 2001):

- Achieve economic goals defined by the organizations, due to past and future investments. Objective linked to efficiency, productivity, reliability, quality and durability.
- The creation of work conditions that will not impact workers health and in which they can exercise their competences in the same time on the individual and collective plan and find valorization possibilities of their capacities. Objective linked to safety, health, comfort, use easiness, satisfaction, interest in work, pleasure.

For Guérin (2001), these two objectives may be complementary, since it is applied a procedure that takes into consideration interactions between two logics: one focused on the social field and other focused on the production field.

2.2.1 The importance of Ergonomics

Ergonomics was constituted from a project aiming to build a knowledge field about the human being in activity, by means of an approach in which the man is simultaneously thought in their physiological, cognitive and social dimensions. (Falzon, 2007)

For ergonomics, it matters not just to study the man at work, but produce useful knowledge to action, whether about the transformation process or the design of work situations or technical objects. It should also develop knowledge about ergonomic action: methodologies of analysis and intervention in work situations, methodologies of participation in design and evaluation of organizational technical devices. (Falzon, 2007)

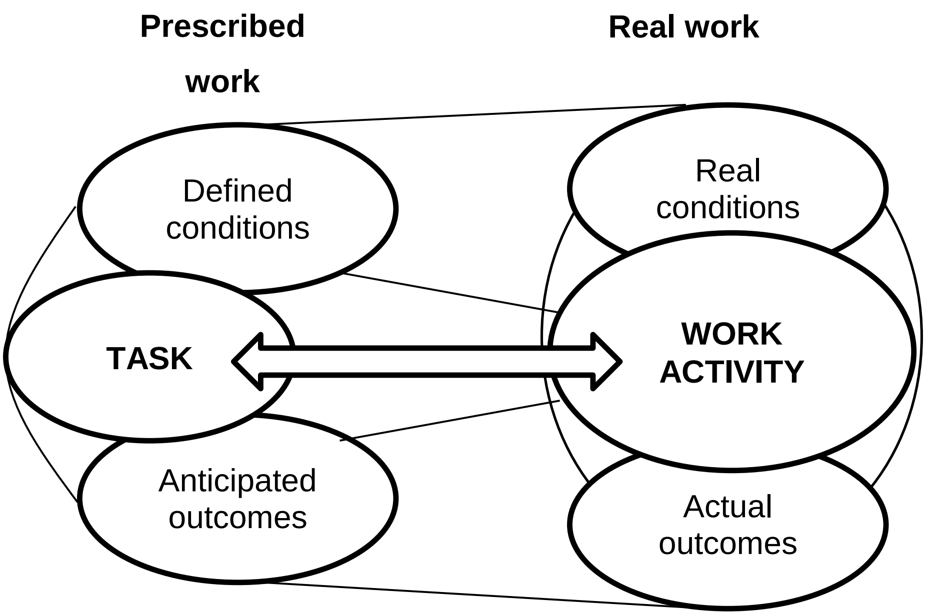
2.2.2 Work, task and activity

Ergonomics has as scientific object the work, but the word “work” encompasses several meanings in its current use. It may appoint working conditions (drudgery, hard work), the result of the work (sloppy work, nice work) or the activity of a certain work process (doing the job, meticulous work, being overloaded with work to do). This multiplicity of meanings demonstrates its fundamental unity. The activity, the conditions and the outcome of an activity do not exist independently of each other. The work is the unity of these three realities. (Guérin, 2001)

Task is what one has to do, what is prescribed by the organization. The prescribed task is defined by a goal (anticipated outcomes) and the conditions for its realization (defined conditions). Goal is the desired final state and conditions relate to the procedures, time constraints, the resources made available, the characteristics of the physical environment, cognitive and collective, and the social characteristics of work. (Falzon 2007) (Guérin, 2001)

Activity is what is actually done (actual outcomes), what one mobilizes to perform the task (real conditions). It is terminated by the goal that one determines for oneself from the task goal. (Falzon 2007) (Guérin, 2001)

Figure 9-Prescribed work and real work



Source: Adapted from Guérin (2001)

The work analysis is the analysis of the overall system; the ergonomic analysis is an analysis of the activity that confronts the analysis of the other working elements. The task is not the work, but what is prescribed by the organization to the operator. As an external prescription, it determines and constrains his activity, but at the same time, it is essential for him to operate, since when determining your activity it authorizes him.

The operator develops his activity in real time according to this framework: the work activity is an adaptation strategy to the actual work situation, the object of prescription. The distance between what is prescribed and what is real is the concrete manifestation of the contradiction always present in the act of work, between "what is sought " and " what the thing that asks." The analysis of ergonomic activity is the analysis of strategies (regulation, anticipation, etc.) used by the operator to manage this distance, meaning, the analysis of the task-man system.

2.2.3 Ergonomic action methodology

Daniellou & Béguin (2007) indicate a methodology that can be followed in ergonomic projects that includes many relevant elements to project development, including the fundamentals of ergonomics, the ergonomics knowledge and the ergonomic analysis components.

2.2.3.1 Fundamentals of ergonomics

The ergonomic action is based on a set of fundamentals, common denominators for ergonomic action processes (Falzon, 2007). Here are the elements that constitute the basis of ergonomic action:

- **Ergonomics, a discipline in course of action**: an essential feature of every ergonomic intervention is that it is not satisfied to produce knowledge about work situations, it seeks action. This common perspective of action may apply to several objects: an existing work situation, future work situations, and a class of situations. As appropriate, the object situations of action are, or not, the same which are the object of analysis. This transformative perspective meets criteria on operators' health and on the effectiveness of productive action. The ergonomic action on work processes aims, at the same time, effects on individuals and effects on the organization. Regarding health, it cares about the physical integrity of workers and the subjective relationship of employees with their work (the suffering that emerges). This is to limit the negative effects of work or even perform a positive role in building the health of each worker. Regarding effectiveness, it is not restricted to the criteria described by tools of management, but also to the risk prevention for facilities or population, the due cost of damages to people's integrity or the exclusion. The criterion of effectiveness demands attention on the diversity of logics in action and the actors playing according to these particular logics (clients, management, employees, population).

- **Problems' definition**: the construction of problem solving is an essential component of action for an ergonomist, problems to solve are not a given data that has been already formatted when the action is requested. The demand analysis is an essential source of information to define the action criteria and evaluate the intervention's feasibility.
- **The Intervention (articulating various points of view and mobilizing a variety of actors):** interactions that the ergonomist establishes with other actors, both to characterize the existing situations as to implement transformation processes, they are characteristics of the intervention. In ergonomic intervention, the characterization of the initial state (diagnosis), the definition of state-purpose and nature of the process to implement are co-production between the ergonomist and other actors**.**
- **Articulation between existing understanding and action over the future:** every ergonomic intervention in a situation aims to contribute to the definition of a more favorable future situation, whether in the case of a limited transformation in the same situation or in designing new ways of working. Every ergonomic intervention assumes that it is possible to refer to existing situations presenting certain characteristics aimed by the project. The ergonomist scales his contribution considering a variety of factors such as the nature of the initial demand and the challenges identified; the position of who asked the change; the identification of the brakes and potential allies; the deadlines set for ergonomist action and the resources made available; the margins of financial and social maneuvering; the ongoing projects.
- **Ethical References**: ergonomist's action is scaled by a representation of the functioning of man and of society and, thus, by values. Some ethical elements are clarity about objectives, methods and tools employed, the arrangements for intervention's return; compliance with the missions assigned to workers' representatives; and the operators' agreement for all observation or policy involving them; the elimination of invasive or traumatic methods; the joint

consideration of productive performance and cost to the people; the priority return to the operators from observed findings about their activity and their agreement before disclosing these pieces of information to the organization; discretion regarding personal information collected; the respect to industrial secrets negotiated, the obligation to inform the occupational physician and the employer of serious health risks identified in the course of an intervention.

2.2.3.2 Ergonomics knowledge

The ergonomic action mobilizes fields of knowledge from different backgrounds and whose validity does not obey the same rules of verification. There is a crucial challenge throughout every ergonomic intervention: for the effectiveness of its action, it has to mobilize existing knowledge and methods besides remaining available for the discovery of dimensions that these fields of knowledge and preliminary methods were not allowed to predict (Falzon, 2007). Hereupon following, the knowledge required for ergonomic action:

- **General knowledge about human beings and their activity**: there is knowledge about the characteristics of human beings and about their functioning, supported by disciplines such as physiology, psychology, sociology and anthropology.
- **General recommendations or ergonomic standards**: a limited number of areas, such as anthropometry and lighting in workplaces, the knowledge is sufficiently stabilized to be expressed in the form of general guidelines or standards.
- **Database of situations**: the ergonomist has a database of situations collected by himself, either through his experience or through the account of other ergonomists.
- **Knowledge about the activity of the other actors to facilitate ergonomist positioning**: an intervention from the ergonomic action takes place in processes of collective action, enhanced and influenced by the ergonomist, who must therefore be able to identify other actors involved and put his action in the relation with them, so that he favor the achievement of an assigned mission.

- **Methods to characterize existing situations**: to characterize the existing work situations, the ergonomist has several methods.
    - **Work Analysis**: understanding the work cannot be limited to the observation of activities. Indeed, the activity in each work situation is integrative, marked by a diversity of constraints related to the general operation of the organization, of which the operator involved may or may not be aware. The ergonomic work analysis assumes that, prior to analyzing the activity, it is necessary to identify the network requirements that guided the decisions in the corresponding sector to address the problem. Methods of job analysis comprehend, therefore, beyond analysis of activity, operation methods of the organization and the representations of the actors.
    - **Differential questioning on the activity**: the competencies that the ergonomist gets to talk to the operator while observing its activity can also be mobilized to formulate questions outside the time of the activity in question. This competence is useful to dialogue with operators about rare occurrence incidents that the ergonomist has no opportunity to observe. One should not interview the operator about a class of situations, but about a specific condition.
    - **Intervention methods in the design of new situations**: the knowledge of existing situations is not sufficient to evaluate the proposed solutions in a design or redesign process. The ergonomist needs to have methods available, allowing him to anticipate the effect of the implementation in the working means. To do so, one uses, in particular, simulation methods.

2.2.3.3 Ergonomic analysis components

Methods described above aim to understand the actual work, these methods are implemented in the framework of ergonomic intervention (Falzon, 2007). Hereupon are the components that must be taken into account during the ergonomic intervention:

- **Demand Analysis**: this step assumes that the ergonomist meets a variety of actors who bears a part of history or challenges , in order to identify the history of demand and the context, the actors involved, in addition to the responsible for the demand who contacted the ergonomist and the attempts of solutions already performed, to identify the challenges that the question encompasses in a variety of areas (economic, human resources, health), and people who are able to take the initiative, to collect information that allows to objectify problems raised, but also existing representations; identifying the representations that actors have about the ergonomist and his potential contribution; identifying the margins maneuvers already explicit, those that might be identified, the constraints to be respected and risks that intervention entails; allow the ergonomist to evaluate the feasibility and relevance of his intervention, to propose a reformulation of goals and modalities of action.

- **Choice of situations to consider**: is pertinent to clarify the issues raised. Not always the situations that were explicitly mentioned in the initial demand must be the only thing to consider. The assumptions that guide these choices come at the same time from the demand analysis and from analogous situations database.
- **Analysis of technical process and sources of prescription**: for selected sectors, it is necessary to gain an accurate understanding of the technical process and the procedural rules that govern the organization. To discover the technical process, it can be used the explanations of the observed operators, as well as general technical documents or internal material. Regarding the requirements, one will seek to identify ways of how the work is prescribed (definition of tasks, operational modes, *a posteriori* control of the results).
- **Activity analysis or the characterization of situations**: the precise observation of work situations is structured quite differently according to the objectives of the intervention. When the demand refers to problems found in existing situations, this demand will guide the study, in view of formulating a diagnosis. The approach is different when a demand does not refer to a current problem (designing a new project).
- **Observation under a framework of a specific demand**: when the demand is entailed by difficulties reported in a work situation, this demand guides the activity analysis, which can be distinguished into two phases.
    - **Free observations**: after the agreement of people involved, there is the work situation in its entirety and makes up a conversation with

operators. Seek are differences between what was described and what is actually observed in reality. Attention is given to the forms of production variability and context for individual or collective responses that they give operators and forms of cost that these operational modes may entail. Examines the census operations and real flows, the interactions between operators, the use of tools, the job results (including waste) and traces of the work (in technical devices, the clothes, the people). Carried out a pre-diagnosis, which relates determinants of activity, some of its features and some of its results or effects.

  - **Systematic observations**: from the assumptions made in the pre-diagnosis, the observations are focused on the intention of validating them. For this, it can be used one of the methods of activity analysis. Formulated results from the analysis are then presented to the operators involved, whose comments can enrich and validate the proposal. Systematic observations and their validation allow the pre-diagnosis become a diagnosis.

- **Validation and diffusion of findings**: the findings, or even the diagnosis are produced and qualified to be disseminated in the organization. In selecting the recipients of these findings, two groups are targeted, the group which has the power to influence a minimal transformation in the short or medium term, and the group that has a strategic role in setting guidelines in the long run.

2.2.4 Project management and the conception of work systems

Ergonomics always aimed to influence the design or redesign of the working media. Initially, this contribution took the form of recommendations after an analysis of existing conditions. Gradually it was identified that, for the design of future situations, methods to collect knowledge of existing work were not applicable to future work, and for this reason, new methods were developed. (Daniellou, A ergonomia na condução de projetos de concepção de sistemas de trabalho, 2007)

In ergonomic design, the work that is the subject of the intervention ergonomist does not exist yet, the activity cannot be analyzed; therefore, methods of approach to future activity should be mobilized.

The challenge of the future activity approach is not to predict in detail the activities that will be developed in the future, since it is impossible to predict the natural activity of a particular operator using the system, the challenge of this approach is to predict the space of possible forms of future activity, i.e., to assess to what extent the design choices will facilitate the implementation of operational modes compatible with the chosen criteria, in terms of health, productive efficiency, self-development and collective work.

Ideally, the design makes possible various operational modes, acceptable ways from the point of view of the chosen criteria, instead of defining only one way of acceptable operation. This flexibility allows to better consider the diversity and variability of situations and operators, and also enables the workers involved to change operational modes, avoiding constantly ask the same functions of the group. It may also be desirable that the design precludes certain operational modes due to the risks they cause.

The main aspects of project management capable of producing a quality design is the implementation of a collectivity, bringing together the different responsible characters of the various relevant competences and functions (finance, product, production, environment, quality, human resources); a project approach to design not only the technical aspects, but the set of all necessary areas to make the system works; a definition of project objectives containing a consideration of existing and future population of workers (age, gender, skill level, health condition) and a decision regarding the desired future organization (level of autonomy, versatility, skills development, forms of cooperation between functions), as well as about the material conditions of work (reduction of certain harmfulness known).

In order to integrate a consideration on the future activity in different stages of design, it is necessary to prepare the proper simulation conditions. As it is not possible to observe the activity in the system that is under design, it should be sought existing situations whose analysis will clarify the objectives and conditions of the future activity. Such situations are usually designated by the name reference situations.

- **Analysis of reference situations**: habitually, one seeks many kinds of reference situations.

1. Situations in which functions that should be covered by the future system are currently ensured under another way. These reference situations will allow, in particular, to detect sources of diversity and variability (from the raw crafted, the client demands, the tools, the context of workers involved), that could be overlooked in the design process.
2. Existing situations embracing some of the technical or organizational features of the future system. In general, there is no strictly similar system, but one piece of the solution can be adopted elsewhere. The analysis of these cases will detect the sources of variability especially linked to technology (tuning, malfunctions, crashes) or to the organizational forms adopted. The choice of these situations, therefore, assumes knowledge of the families of solutions considered by the project, which can evolve over its development.
3. In certain cases it may also be necessary to look for reference situations corresponding to geographical or anthropological context of where the project will be implemented. This need is evident in the case of technology transfer between continents, but can also arise, for example, in the case of a transfer between a large and a small company, or when it is moving to a very different region.

The ways that analysis of reference situations may assume are numerous: in some cases, will consist in field visits, in others, will include interviews and documents study, and finally in certain cases, it will be possible to perform actual activity analysis.

- **Census of characteristic action situations**: the main result of the reference situation analysis is a census of how variability may appear in the future system. It is then necessary to perform a work of transposition, to determine which sources of variability observed in these situations are able to appear in the future system. The formalization of this analysis is submitted, in particular, to a checklist of likely characteristic action situations. This is a census of the kinds of situation that operators will probably have to manage in the future: some correspond to normal operating situations, installation, provisioning, tuning, cleaning, maintenance, changes of tool or production; others correspond to the inevitable production variability (variety of sizes of products, product sensitive to heat), or incidental variability (breakage of a tool, deregulation, power cut). Each action situation chosen feature will be defined by: goals (tasks to fulfill), production criteria (quality, deadline, consequences in case of error), professional groups involved and factors that can influence the internal state of the people (night work, exposure to cold).

- **The uses of characteristic action situations**: the census of likely characteristic action situations in the future system is the essential tool in all steps of the design process, since it allows to establish a bridge between the activities effectively analyzed and the approach of future activity. Uses can be cited, such as:
    - In the phase of project objectives definition, of programming, of descriptive memorials, the characteristic action situations enable a better assessment of consequences from certain strategic choices.
    - The characteristic action situations play a key role in drafting design references.
    - The list of characteristic actions can be used to evaluate the project after its kick-off, the analysis of the real activities allowing to check the predictive value of the methodology, the situations that had been correctly anticipated and those that had not been identified.
- **References for the designing process**: they assign the formalization that the ergonomist makes its findings on previous situations analyzed. Usually, it involves three aspects:
    - Descriptive references, by which one calls attention to certain design challenges, without assuming the solutions that will be developed.
    - Prescriptive references, in areas where the state of knowledge is sufficiently stabilized (anthropometry, lighting, stereotypes respect) enabling to prescribe a result.
    - Procedure references, by which one prepares the intervention sequence. It points out next steps of the methodology and indicates the resources needed for these steps. Therefore, one previously structures future interactions with other actors of the design.

3 INFORMATION GATHERING

To be able to design the physical layout and the user rules of the New Project Room, interviews and reference situations were used to gather information.

Interviews were conducted with Professor Eduardo de Senzi Zancul, the professor responsible for the implementation of the Project Room, and with monitors of the current Project Room.

The main reference situation used is the current Project Room. It will be possible to analyze the characteristic action situations in which the room is expected to be used. By observations, it will be possible to obtain the information needed for the next stages of layout development and rules of use and safety. Other reference situations used are places which have similar use and purpose to the Project Room.

3.1 Interviews

The interviews were the main basis to understand the expectations and opinions of the actors who have more relevant knowledge to the design of the Project Room.

3.1.1 Professor Eduardo de Senzi Zancul

Professor Eduardo de Senzi Zancul, professor from PRO department, is responsible for implementing the Project Room, therefore, his opinions and information are essential, since the physical arrangement must be aligned with his expectations and ideas.

In the interviews it was possible to understand the purpose of the Project Room: be useful as a space for students to carry out projects of any type, although there will be some features primarily intended for projects of product development, such as softwares and equipment. Its use is not limited to projects related to scholar disciplines, and the laboratory is expected to be available 24 hours a day, every day of the week, despite of the fact that it was not carefully thought how to operationalize this availability.

Professor Eduardo de Senzi Zancul cited as reference two places in the U.S. that are used as the main inspiration for what he hopes will be the Project Room of PRO: the Design Loft located at Stanford University and the Radicand Labs, both will be better described later in the reference situations section. It may be noted that both places are quite flexible, allowing group meetings, ideas development and the manufacturing of pieces and prototypes.

On the future physical arrangement of the Project Room, the first constraint is the availability of space in the new building. The furniture that will be available is not yet set. Then, the suggestion was to use as planning basis the furniture from Steelcase Company, which is specialized in producing ergonomic office furniture worldwide.

In addition to the furniture, it is planned to be available equipment and machines that assist users in projects development such as computers with different softwares (e.g. softwares for Product Lifecycle Management, 3D Modeling, Mathematics, Statistics and Simulation, Quality Function Deployment, Failure Mode and Effect Analysis, Project Management, Process Management), high processing capacity computers for image processing, eyetracking equipment, Kinect device, 3D scanner, conventional scanner, 3D printers, sound level meter, light meter, thermometer, integrated hygrometer, anemometer, anthropometer, anthropometric tape, heat stress meter, electronic tape.

The physical arrangement proposed by the Professor was the division of the Project Room into smaller rooms according to its uses, focusing on different activities that can be performed in the new room. With at least two meeting rooms for groups, with sofa, tables, chairs, whiteboards and computers; a ergonomics room, for ergonomic analysis with computers and the proper equipment; an image processing room, with 3D scanner, high capacity computer, Kinect device; a room for computers with softwares and 3D printing. Another suggested, but not essential, site would be an area for coffee-break.

3.1.2 Current Project Room monitors

The monitors of the Current Project Room provided important information on the use of it, since they are responsible for the room and for its operation. The monitors Bruno Kawasaki, Armando Nader, Gabriel Delage and Eloi Pattaro were interviewed.

The same questions were asked to all monitors, since each monitor is responsible for the Current Project Room in different hours, so each one may have observed different situations.

All monitors are responsible for opening and closing the room and watch over it. However, other tasks vary from monitor to monitor, these tasks that are not performed by all monitors include: maintenance, preparation, assistance to users, supervision, replacement of raw materials and cleaning 3D printers; help to users in 3D modeling; organizing the room, maintenance, installation and updating of softwares.

The single source can provide real risks of accidents are 3D printers, since its movements are controlled by the computer and the extrusion nozzle and the printing table reach high temperatures. So far there has been no accident in the Project Room, however, there was an occasion in which one of the printers overheated and started to release smoke. When the monitor noticed this, he quickly turned it off. This printer eventually was discarded. In another situation, due to the large number of projects to be printed, there were moments where the 3D printer was unattended by monitors, the group that was using the 3D printer did not realize that the raw material was over, which eventually resulted in a momentary default of the printer.

Although there are no use and safety standards formalized, the monitors inform guidelines for users. Attention such as to secure long hair and use pliers whenever handling materials extruded by the 3D printer and constant supervision when the 3D printer is in use.

As recommendations for the organization of the physical arrangement, the monitors suggested: the existence of a roll of raw material for 3D printer, so one does not need constant replenishment and the lack of raw materials does not cause problems to the 3D printer. Currently, there is only one roll of this raw material, which is cut into pieces so that there is material available for all 3D printers; the slightly higher placement of the printer, such as when printing it is required constant supervision, makes it necessary that the viewer stays at a bent position, which can be uncomfortable; positioning more bins near the 3D printers for material disposal; a site for organizing and storing tools and equipment; a site for exhibition of printed pieces, so they are not spread through the room; a site for tools and cleaning supplies from printers.

3.2 Reference situations

In the New Project Room case, the reference situations are spaces that present similar use or similar equipment.

Due to the fact that they have similarities with the New Project Room, the reference situations analysis provide a variety of inputs to design the physical arrangement and the rules for using it.

3.2.1 Current Project Room

Currently, the Project Room is located on the first floor of the building of the Department of Production Engineering from Escola Politécnica da Universidade de São Paulo (PRO), where it was located the building’s canteen.

The room can be divided into four rooms: the main room (where there are located tables, chairs, computers, 3D printers), two meeting rooms for groups (separated by walls but no door) and a storage area (separated by a glass door and where servers are located, and a cabinet).

Figure 10-Current Project Room

Source: Author

The current composing elements of the project laboratory are:

Table 9-Elements of the current Project Room

Element	Quantity
Small table	5
Big table	9
Chair	25
Computer	7
3D printer	4
TV	2
Whiteboard	1
Server	3
Cabinet	1
Shelf	2

Source: prepared by the author

To improve the analysis of the Current Project Room physical arrangement, it was developed a quick sketch of the room with the online application Homestyler (Autodesk, Inc, 2013). Although it is not possible the exact representation of the physical arrangement due to the need to use existing furniture and objects inside the platform, it is possible to use furniture and similar objects that properly represent the dimensions, proportions and distances in the current project area. For the purpose of this model, which is only to allow viewing the space in the room as it is currently used, the model built in Homestyler is enough.

Figure 11-Current Project Room plan

Source: prepared by the author

Figure 12-3D Model of the Current Project Room

Source: prepared by the author

It was possible to observe the use of the Current Project Room in two different characteristic action situations. The observations made in the Current Project Room in these situations provide information about the Project Room in actual use, making it is possible to observe the interaction between the physical arrangement and its users.

The two characteristic action situations observed were the use during a lecture and the use of 3D printer in free time.

3.2.1.1 Use during a lecture

On September 17, 2013, from 08:50 PM to 10:30 PM, it was possible to watch a class of discipline “PRO2719 - Materials and Production Processes III”, offered to students from Design course, taught by Professor Uiara Bandineli Montedo and the discipline monitor Bruno Kawasaki.

The class was held in Project Room of the current building of PRO. The room was used for the first time by this discipline. The class, consisting of approximately 40 students was divided into two, so that it could better accommodate all attendees. In total there were 18 people (15 students, a professor, a monitor and the author of this dissertation).

The purpose of this class was to introduce the design students to the 123D Catch, platform that allows transforming photos into 3D models by generating a mesh of points. This platform can be used in computer (installed on it or as web application) or smartphone (in the application).

Students were gradually coming into the room and settling in their seats. Some of the students could not sit in a chair that had easy access to tables so that they used the chairs in front of computers. However, as the tables of computers are turned back to the TV, they could not use it because it would be back to the TV, to the professor and to the monitor, which made it uncomfortable performing notes, since there was no table.

At the beginning of class the professor made general explanations of the discipline. Then, the monitor played the tutorial video on the TV about the use of

123D Catch. During both presentations the door was open, since the day was a little warm and there is no air conditioner in the room. There was a group who chatted near the room and the noise caused some troublesome. Moreover, the constant noise from servers that are inside the room, separated by a glass door, could also be heard.

Figure 13-Students attending the class and using the computer

Source: Author

Due to the high location of the TV, all participants seated could follow what was played on it, since the maximum distance from an observer was at most 3m. Although it was night and there was no natural light, artificial lighting was sufficient for performing all activities.

At the end of the lesson, students sat with their respective groups working on computers in order to become familiar with the 123D Catch. After interacting with the platform, the class was ended.

3.2.1.2 Use of 3D printer in free time

On September 30, 2013, from 7:30 AM to 9:00 AM, it was possible to observe the use of 3D printers in free time. It was chosen to observe a situation in which an object was printed by the 3D printer, since that in this situation, more unusual activities are conducted. However, in the period in which this observation was planned, there was no planned print of any piece. For this reason, a simulation was performed, the author of this dissertation has made a test piece printing, simulating a student who had already modeled his piece and would like to print it. The simulation was previously scheduled with the monitor Bruno Kawasaki, who had been informed of the circumstances.

The piece printing in the 3D printer Metamáquina 2 occurs by deposition of material, in this case the PLA (polylactic acid). The piece to be printed is formed from the deposition of molten material in several layers one above the other, with the cooling of the material, it hardens and the part is formed.

When he arrived to the room, the monitor washed the glass plate on which the printing is performed, to degrease the surface, he used soap and water and it was possible to do it in male bathroom near the Current Project Room. The glass plate was dried and put into position, the computer and the 3D printer were connected, the software Pronterface was opened with the test model that would be printed and a plier was used for the removal of waste material from the previous print from the extruding nozzle of the 3D printer.

Figure 14-Monitor calibrating the 3D printer Metamáquina 2

Source: Author

After that the calibration of the 3D printer nozzle was done, so that it lightly touches the glass plate. The software control allows the 3D printer nozzle to be moved in 1 mm up or down and 0.1 mm up or down. For calibration, it was placed a sheet of paper on the basis of glass. The nozzle of the printer was lowered with movements of 1 mm down until it gets close to the sheet without touching it. From this point, movements of 0.1 mm were used. In each movement, it was observed if the paper sheet could still be moved until when the sheet could not be moved. This indicated that the nozzle was calibrated. For the removal of the sheet, the nozzle was raised by 0.1 mm, being possible to remove the sheet and again lowered to 0.1 mm.

With the start of printing in the software, it was necessary to wait for a few minutes due to the heating of the extrusion nozzle of the 3D printer. Once the extrusion nozzle was heated, the printing process started. The 3D printer plate, where the piece is formed, moves on an axis, perpendicular to the user who observes the front of the printer. The nozzle of the 3D printer, that deposits the material, moves in a plane parallel to the user.

While printing, there was deposition of material off-site the printing area, due to printer failures. The printer was paused and the material was removed with pliers, because the hot temperature of the material facilitated its removal.

In about 10 minutes the test piece was printed. After two minutes of cooling, it was possible to detach the piece from the glass plate with the plier. The 3D printout had the expected characteristics of quality and printing was satisfactory.

Figure 15-Printed pieces on the 3D printer

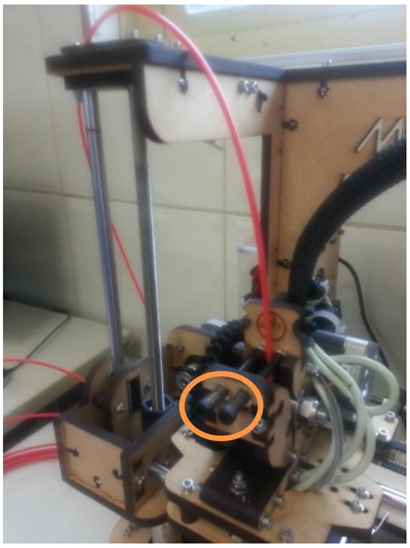
Source: Author

Throughout the printing period the presence of a user is required, as in the case of any event, such as a printing error, or defect, printing can quickly be paused or canceled and a solution can be found. According to the monitor, in some cases, depending on the piece, the nozzle of the printer does not rise up a layer, trying to deposit more material in the same layer. In this case, the solution found so far was to make changes in the model at the software.

If the 3D printer is not calibrated in the horizontal plane, it can occur that a piece gets printed with errors. To solve this problem, there are threads that when rotated calibrate the 3D printer.

The monitor demonstrated how the exchange of raw materials (PLA) is performed. It must be pressed with enough force two buttons until a piece pops up and one can replenish raw material. Due to the existence of only one roll of PLA in the Current Project Room, the monitors need to make replenishments very frequently, which should be avoided by the difficulty of execution.

Figure 16-Buttons of the 3D printer that must be pressed to replenish raw material



Source: Author

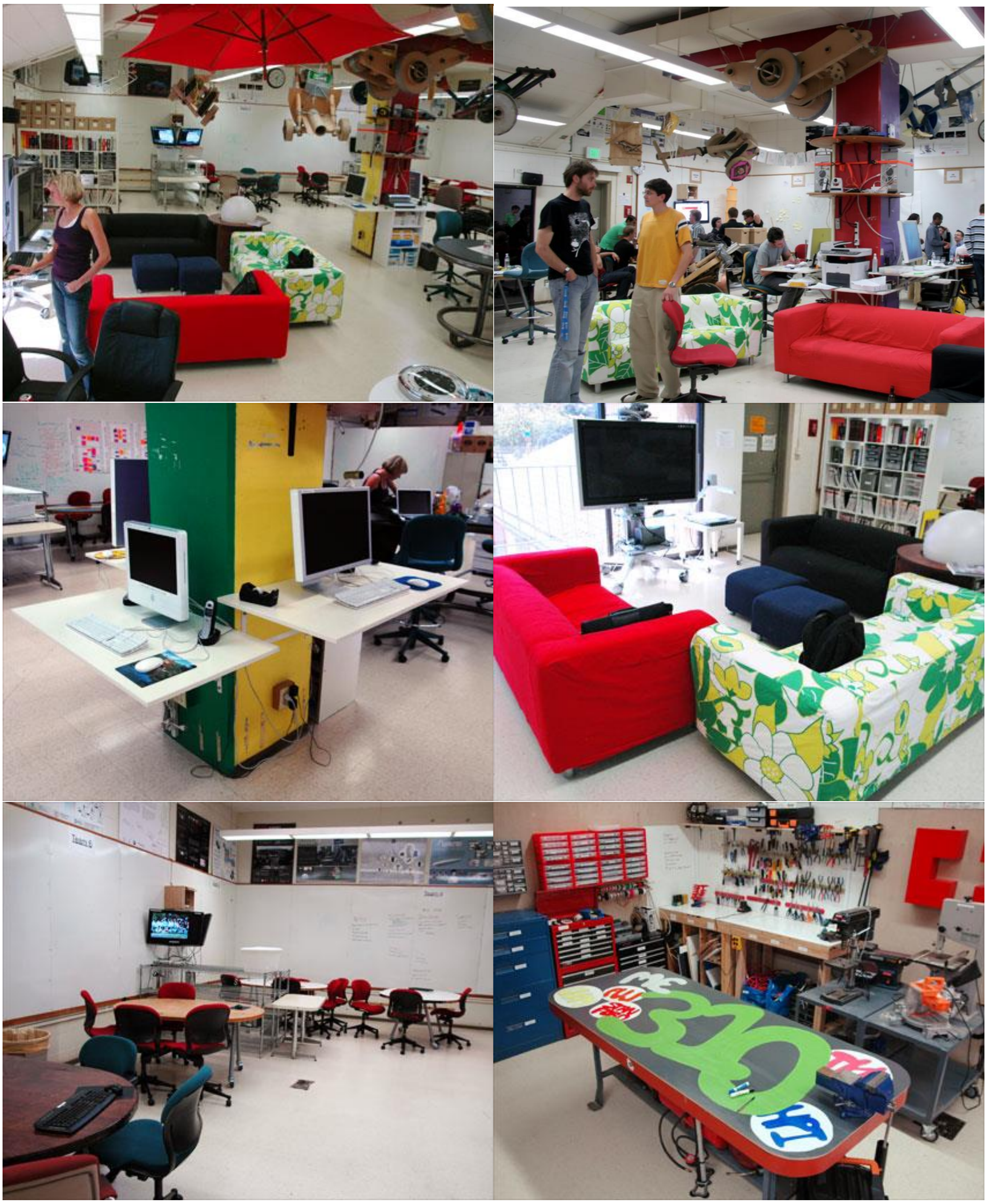
As all the printing process requires observation, it could be appropriate that the 3D printer was supported in a slightly higher level, since the current position puts the user in an uncomfortable position to observe and check the extrusion nozzle of the 3D printer. Currently, only one computer can be connected to a 3D printer; however, in the New Project Room it will be possible to connect two computers to a 3D printer.

3.2.2 Design Loft at Stanford University

Stanford University, located near the city of Palo Alto in the state of California, in the U.S., is internationally renowned for being a university that encourages and promotes entrepreneurship and innovation among its students. In one of its disciplines, “ME310-Design Innovation”, global companies propose challenges for students from Stanford and other top universities around the world in creating innovative designs. From this course, it has been designed projects of personal air conditioning equipment and video conferencing innovative appliances. (Stanford University, 2013)

For the discipline, the university offers the Design Loft, a place where it is possible to develop product projects.

Figure 17-Design Loft at Stanford University



Source: Stanford University (2013)

The Design Loft has its physical arrangement organized by use, in which space is composed of a variety of cells, since in each cell, the available resources are those necessary to conduct all activities in a step of project development.

The identifiable cells are: videoconferencing, consisting of sofas, TV and video conferencing appliances; group meeting cell, consisting of sofas, tables, chairs and TV; quick prototyping cell, composed of bench, various tools and machinery; computer cell, composed of computers, tables and chairs.

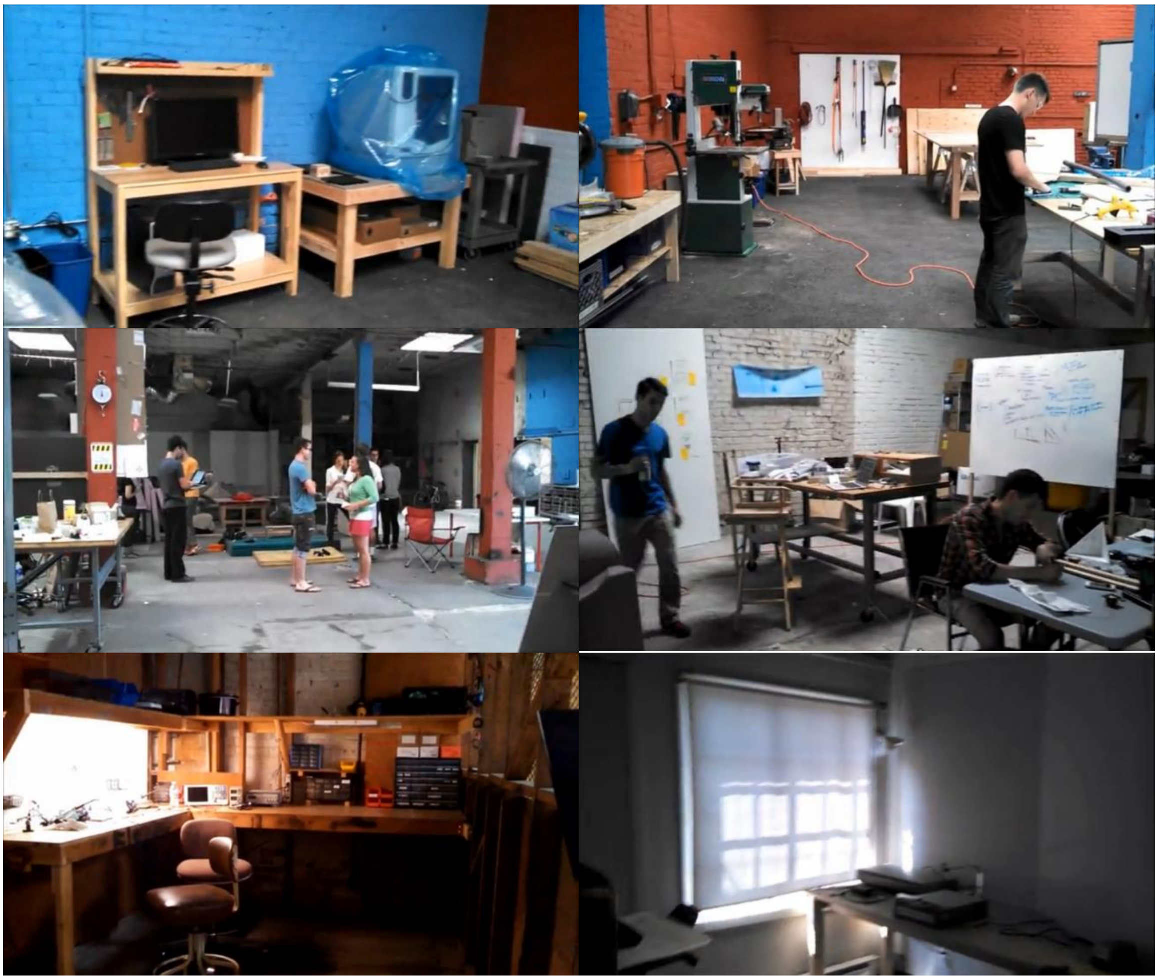
It can be noted that in the Design Loft, one optimizes the space in all its dimensions. The walls are used as whiteboards, products and parts are exposed on the ceiling, encouraging creativity, the chairs and some tables have casters that allow moving according to the situation of use and the use of walls between the cells are minimized. The space is very open and creative, giving freedom to the movement of its users.

3.2.3 Radicand Labs

The Radicand Labs considers itself a collaborative platform for entrepreneurs and freelance engineering developers. It is located in Redwood City, in the state of California, in the U.S. To access the Radicand Labs it is necessary to pass a highly selective process in which qualified individuals are only accepted. On the month of October 2013 there were 38 members accepted. (Radicand Labs, 2013)

The members of the Radicand Labs have access to the consultancy of the best professionals from engineering, design and computer science courses at Stanford University and the area is equipped to ease collaboration and quick prototyping of their projects.

Figure 18-Radicand Labs



Source: Radicand Labs (2013)

In the Radicand Labs, the physical arrangement is divided into cells, such as the Design Loft at Stanford University. However, the available space in the Radicand Labs is considerably bigger.

The identifiable cells are: 3D printing cell, composed of 3D printers and computers; quick prototyping cell, composed of bench, various tools and machinery; group meeting cell; composed of sofas, tables, chairs and whiteboards; electronic cell, consisting of electronic equipment; image processing cell, composed of 3D scanners and other image equipment.

4 PHYSICAL ARRANGEMENTS

Throughout the development of the project, the six principles of the physical arrangement planning suggested by Muther (1955) (principles of full integration, of the minimum moved distance, of flow, of cubic space, of satisfaction and safety, of flexibility) will be the basis of analysis. Some of them, such as the principles of full integration, of satisfaction and security and of flexibility, will be considered with utmost importance, given the nature of the project.

4.1 Physical arrangements elements

In the New Project Room, the five basic elements upon which a physical arrangement is planned according Muther (1978) are:

- **(P) Product**: in the case of the New Project Room, it is understood as a product the final result of processes performed in its area. One cannot define a single type of product. Although there is only one type of physical product, the pieces produced by the 3D printer, not all types of use of the room necessarily result in a printed piece. The final products may include, for example, the model of a piece in a software platform, a class related to product development, a demonstration or training regarding the use of softwares or the 3D printer, a group meeting, the ergonomic analysis of a product, etc.
- **(Q) Quantity**: given the huge variability between the outputs of the processes carried out in the Project Room, it can be said, except on very rare occasions, that each product is unique. Even when the final product is a printed piece or a prototype, the objective of the Project Room is not to produce these items on a large scale.
- **(R) Routing**: although in an organization that manufactures products, the main flows are those involving raw materials, pieces and finished products, which, in the case of the Project Room, the movement of these elements practically nonexistent. The only materials that are moved within the Project Room are the raw materials for the 3D printer, called polylactic acid (PLA), used in a way that resembles a wire, and the printed pieces in the 3D printer. Both materials are reduced in size, and the amount of movements of these

materials is very low. In this particular case, the main flows are those that involve people, since they rather perform different movements to perform different activities. It is not possible to describe all the movements and sequences inside the Project Room, since each person moves differently. So, in this case, it is interesting to record the activities most likely to be performed in the New Project Room.

Table 10-Activities developed inside the New Project Room

Activity	Necessary elements	
Group meeting	Table	Computer
	Chair	TV
	Whiteboard	Sofa
Use software	Table	Computer
	Chair	
Print 3D piece	Table	Computer
	Chair	3D Printer
Do an ergonomic analysis	Table	Thermometer
	Chair	Integrated Hygrometer
	Computer	Anemometer
	TV	Anthropometer
	Eyetracking	Anthropometric Tape
	Sound Level Meter	Heat Stress Meter
	Light Meter	Electronic Tape
Do an image processing	Table	High capacity computer
	Chair	3D Scanner
	TV	Scanner
	Kinect	
Attend a class	Table	Computer
	Chair	TV

Source: prepared by the author

- **(S) Support services**: supporting services shall be performed by the monitors, they perform activities such as maintenance, preparation, assistance to users, supervision, replenishment of raw materials and cleaning of the 3D printers; help users in 3D modeling, organization of the room; maintenance, installing and updating software of computers.

- **(T) Time**: In a traditional organization, which seeks, among other goals, increase production efficiency in their physical arrangement, the time dimension is of utmost importance, since through this dimension it is possible to calculate cycle times, production capacity, among other indicators. However, in the case of the Project Room, this dimension has little importance. The important variables are the hours of operation of the room, the availability of monitors' time, the average time to perform a print, the duration of a project developed in the room.

4.2 Type of process

Among the types of process (project, jobbing, batch or bulk), the one that most suits the New Project Room is the project process.

As the name itself clarify, the Project Room is meant for the execution of projects, and given the freedom that exists in the projects to be implemented, each one is truly unique. Development periods of each project are usually long, lasting from days to months. It is not possible to create a script, each project uses the Project Room in a unique way. There is great variability in the product, and the quantity produced is low. Due to these features it is possible to conclude that the process is a project process.

4.3 Type of physical arrangement

After analyzing the product elements, quantity, routing, support and time/transport, and the type of process the Project Room, the following step is the definition of the type of physical arrangement.

Observed the advantages and disadvantages of each type of physical arrangement, the requirements of the Project Room and the reference situations, the type of physical arrangement most appropriate is something that resembles the cellular physical arrangement.

As noted in the reference situations, which are also arranged in cells, cell physical arrangement provides all the resources necessary for the development of a particular step of product development in a single cell. This type of physical arrangement is beneficial to the New Project Room because it reduces the number and the distance of movements performed by the user, in addition to being a very flexible arrangement, enabling the development of projects.

It should be understood that due to the long period of projects development, each visit that a user or a group of users performs in the Project Room, a limited number of activities is developed, and it may be necessary for these users an exclusive use of some resources for a few hours, such as in a product ergonomic analysis, an image processing or a construction of a 3D model.

A positional physical arrangement does not make sense because people keep fixed and moving resources around them would be extremely laborious. The physical arrangement of the process, although possible, would dramatically increase the number of movements and distances walked. The physical arrangement in line is not possible because for its development it is necessary to have a well-defined roadmap production, which would make the project development extremely rigid and inflexible.

Therefore, considering the benefits presented and the ideas observed in reference situations, cell physical arrangement is the one to be used in the New Project Room.

4.4 Inter-relations not based on the flow of materials

The Project Room does not present requirements of physical arrangement of a traditional organization. By that time, the traditional analysis methodology was enough for the project development. However, in a traditional physical arrangement, which gives great importance to productivity and production costs, the next step would be to analyze the flow of materials, which in the Project Room makes no sense, since the flow of materials is practically non-existent and the productivity and production costs have reduced importance. An alternative in this case is the use of inter-relations not based on materials flow, using factors other than the flow of materials to position the elements on the physical arrangement.

Before classifying which existing inter-relations, it is needed to list what are the relevant resources of the New Project Room to which these interrelationships must be analyzed.

Table 11-List of resources of the New Project Room

Code	Resource
Tab	Table
Chr	Chair
Sof	Sofa
PC	Computer
3dp	3D Printer
TV	TV
Wbr	Whiteboard
Cab	Cabinet
Erg	Ergonomic Analysis
Img	Image Processing
Dor	Door
Wdw	Window

Source: prepared by the author

It is considered "Ergonomic Analysis" those equipment dedicated to this activity (eyetracking, decibel meter, light meter, thermometer, hygrometer integrated anemometer, anthropometer, anthropometric tape, heat stress meter and electronic tape). It is considered "Image Processing" that equipment dedicated to this activity (3D scanner, scanner, high capacity computer and Kinect). These devices have been previously grouped because they present many similarities; they are used for the same type of activity and have reduced dimensions. For elements that need to be placed on a table, as in the case of the computer and the 3D printer, this table will not be considered at this stage as a separate element, it will already be considered with the element that is placed over it, since it is essential the table under these devices.

Thus, it is possible to generate the chart of preferred interconnections.

Table 12-Chart of preferred interconnections of the New Project Room

	Window	Door	Image Processing	Ergonomic Analysis	Cabinet	Whiteboard	TV	3D Printer	Computer	Sofa	Chair
Table	O 5	U	U	U	U	E 1	E 1	U	U	I 4	A 4
Chair	U	U	U	U	U	E 4	E 4	A 4	A 4	O 1	
Sofa	U	U	U	U	U	E 4	E 4	U	U		
Computer	U	U	U	I 2	U	U	A 3	A 3			
3D Printer	U	U	U	U	O 2	U	U				
TV	U	U	E 1	E 1	U	I 1					
Whiteboard	U	U	O 2	O 2	U						
Cabinet	U	U	O 2	O 2							
Ergonomic Analysis	U	U	U								
Image Processing	U	U									
Door	U										

Source: prepared by the author

Table 13-Quantity of interconnections of the New Project Room

Value	Proximity	Quantity
A	Absolutely necessary	5
E	Especially important	8
I	Important	3
O	Ordinary closeness	7
U	Unimportant	43
X	Undesirable	0
Total		66

Source: prepared by the author

Table 14-Reasons to interconnections in the New Project Room

Code	Reason
1	Convenience
2	Storage
3	Necessary to operate
4	Comfort
5	Natural lighting
6	Protection from light and water

Source: prepared by the author

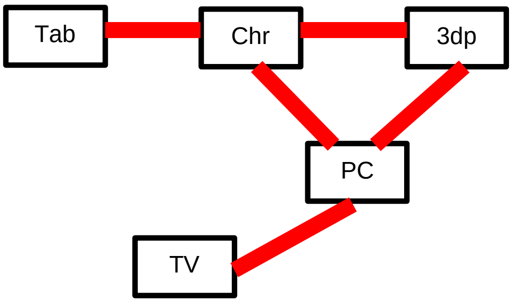
To make the letter of preferred interconnections, the activities to be performed more often in the New Project Room were considered and listed above in the section about the elements of physical arrangement "(R) Routing”.

Although Muther (1978) suggest that the preferred amount of inter-relations of type A should be very low, in this case, only the type of inter-relations between elements that actually need to be close have been considered “A”, either by the need for operation of the elements, or if there is an essential need for user comfort. Regarding the interconnections type “E”, there are some that are related to user comfort and others related to proximity convenience, since that when performing a certain activity, two given elements are simultaneously used. For inter-connections of type “I” and “O”, the reasons included proximity convenience, user comfort, a place for storing materials and a natural source of light from the windows.

After making the chart of preferred interconnections, it is possible to elaborate the preferred interconnections diagram, in order to facilitate the visualization of existing findings in the chart.

It begins by interconnections of type A.

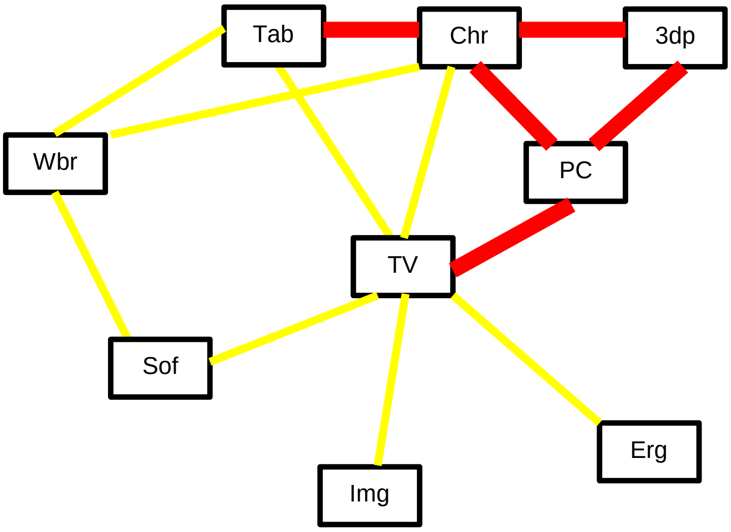
Figure 19-Interconnections of type A in the New Project Room



Source: prepared by the author

Then, interconnections of type E are included.

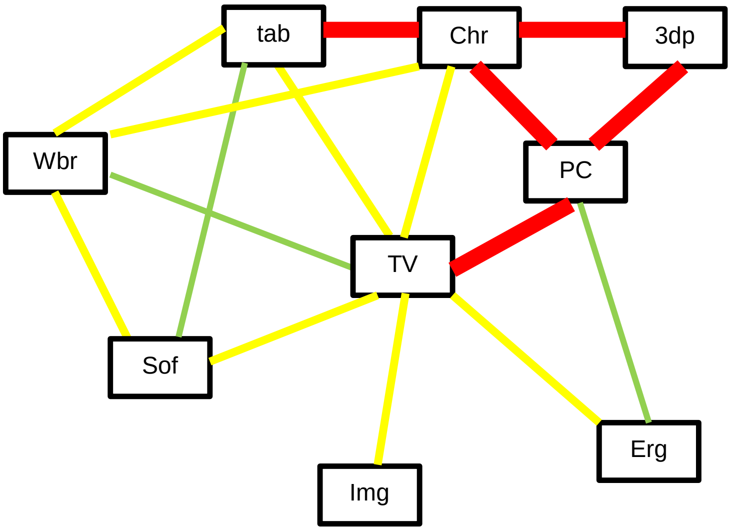
Figure 20-Interconnections of type E in the New Project Room



Source: prepared by the author

It can then comprise the interconnections of type I.

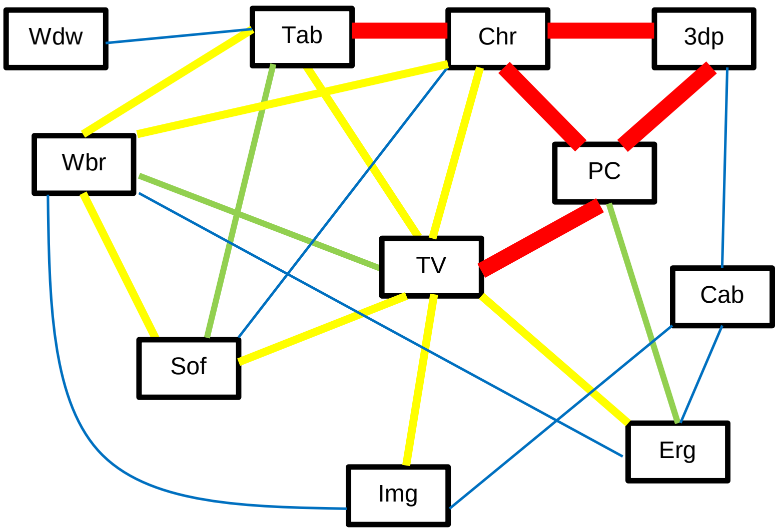
Figure 21-Interconnections of type I in the New Project Room



Source: prepared by the author

And finally include the interconnections type O, then obtaining the preferred interconnection diagram.

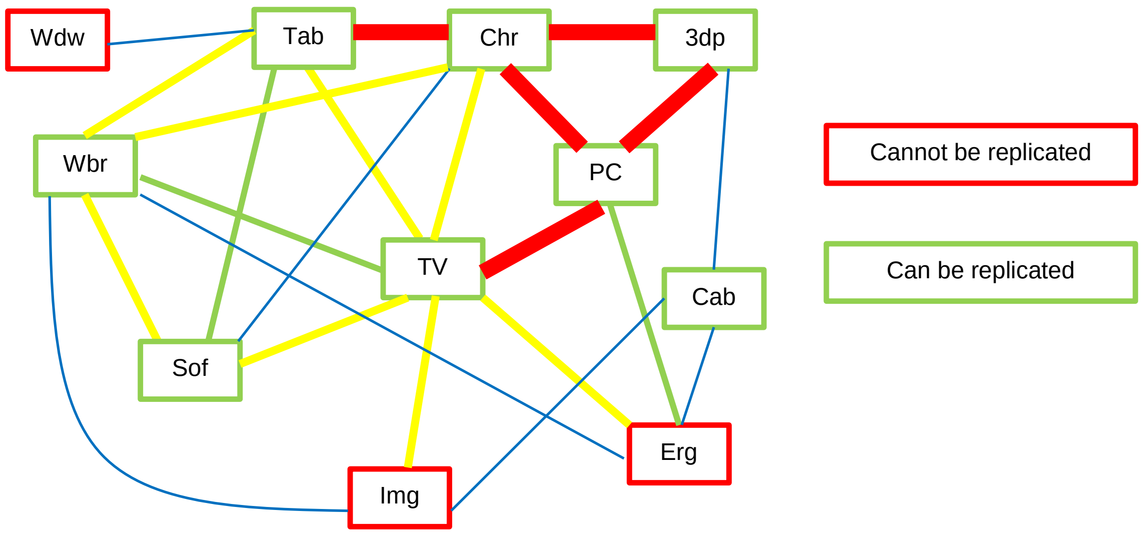
Figure 22-Interconnections of type O in the New Project Room



Source: prepared by the author

Through the diagram it can be seen that there are a large number of intersections between the lines. Although most of the intersections occur between types I and O, and no intersection occurs at interconnections of type A, which makes them less severe, it is possible to avoid many of them, since most of the elements are not unique, meaning, some of the elements can be replicated by purchasing more than one unit of this element, such as a TV, Table, etc.. For other elements, however, there is no point in replicating them, whether the demand for it is not high (image processing and ergonomics), whether there is a physical impossibility (window).

Figure 23-Replicable and Unreplicable elements



Source: prepared by the author

Moreover, at this step it is possible to use the proposed ideas by Professor Eduardo de Senzi Zancul, responsible for implementing the Project Room. As previously defined, the physical arrangement of the New Project Room will be organized in cells and in the interview, Professor Eduardo de Senzi Zancul proposed the physical arrangement of the New Project Room to be organized in cells in which each one would be intended to different activities. Thus, the cells proposed by him were an image processing cell, an ergonomics cell, a computer cell and two group meeting cells.

With this division by cells, it is possible to allocate the mapped activities into the New Project Room on the following way between cells:

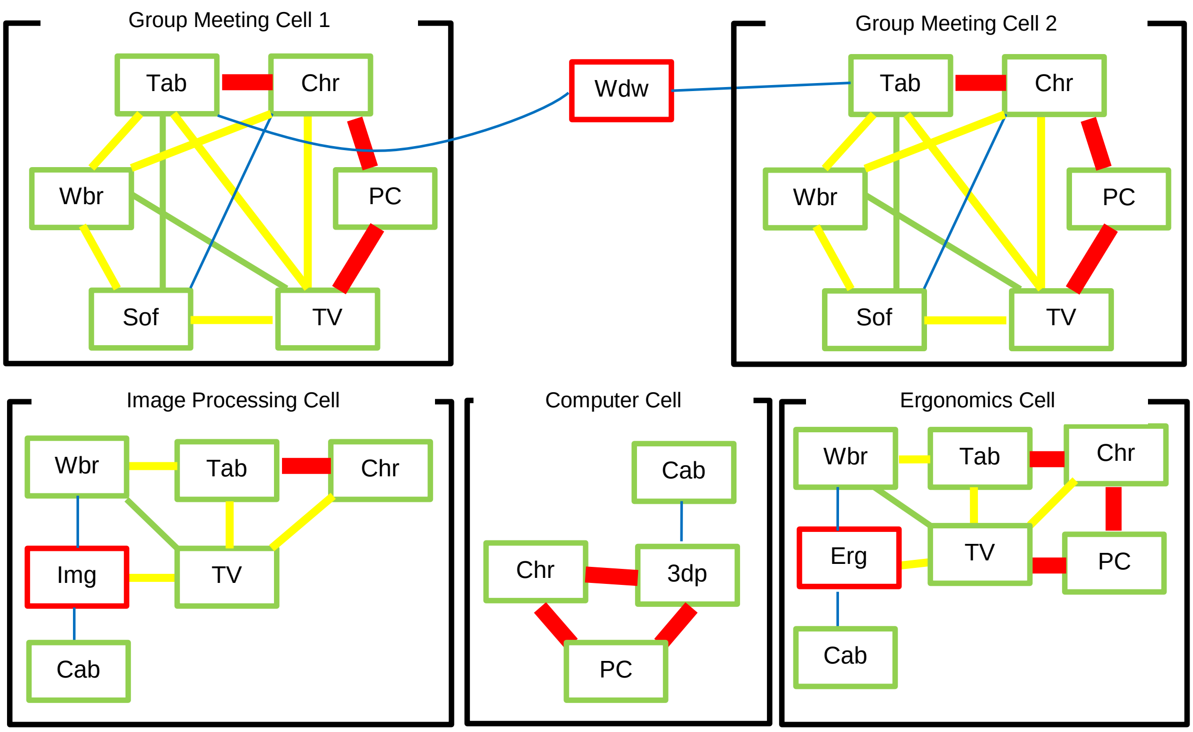
Table 15-Activities allocation in cells for the New Project Room

<table>
<tr><th>Cell</th><th>Activity</th><th colspan="2">Necessary elements</th></tr>
<tr><td rowspan="5">Group meetings</td><td rowspan="3">Have a group meeting</td><td>Table</td><td>Computer</td></tr>
<tr><td>Chair</td><td>TV</td></tr>
<tr><td>Whiteboard</td><td>Sofa</td></tr>
<tr><td rowspan="2">Attend a class</td><td>Table</td><td>Computer</td></tr>
<tr><td>Chair</td><td>TV</td></tr>
<tr><td rowspan="4">Computers</td><td rowspan="2">Use a software</td><td>Table</td><td>Computer</td></tr>
<tr><td>Chair</td><td></td></tr>
<tr><td rowspan="2">Print 3D piece</td><td>Table</td><td>Computer</td></tr>
<tr><td>Chair</td><td>3D Printer</td></tr>
<tr><td rowspan="7">Ergonomics</td><td rowspan="7">Do an ergonomic analysis</td><td>Table</td><td>Thermometer</td></tr>
<tr><td>Chair</td><td>Integrated Hygrometer</td></tr>
<tr><td>Computer</td><td>Anemometer</td></tr>
<tr><td>TV</td><td>Anthropometer</td></tr>
<tr><td>Eye tracking</td><td>Anthropometric Tape</td></tr>
<tr><td>Sound Level Meter</td><td>Heat Stress Meter</td></tr>
<tr><td>Light Meter</td><td>Electronic Tape</td></tr>
<tr><td rowspan="4">Image processing</td><td rowspan="4">Do an image processing</td><td>Table</td><td>High capacity computer</td></tr>
<tr><td>Chair</td><td>3D Scanner</td></tr>
<tr><td>TV</td><td>Scanner</td></tr>
<tr><td>Kinect</td><td></td></tr>
</table>

Source: prepared by the author

Having the list of activities to be undertaken in each cell, and consequently the necessary elements inside the cell, it is possible to determine a new diagram of preferred interconnections. Elements such as window and cabinet, which are not listed in the list of activities, are added to the cells by the affinity presented with it.

Table 16-Interconnections diagram of the New Project Room



Source: prepared by the author

In the new diagram of preferred interconnection, it is possible to observe that the intersections between lines has been drastically reduced, showing that the choice of the physical arrangement per cell is effective in planning the physical arrangement of the New Project Room.

4.5 Alternatives generation

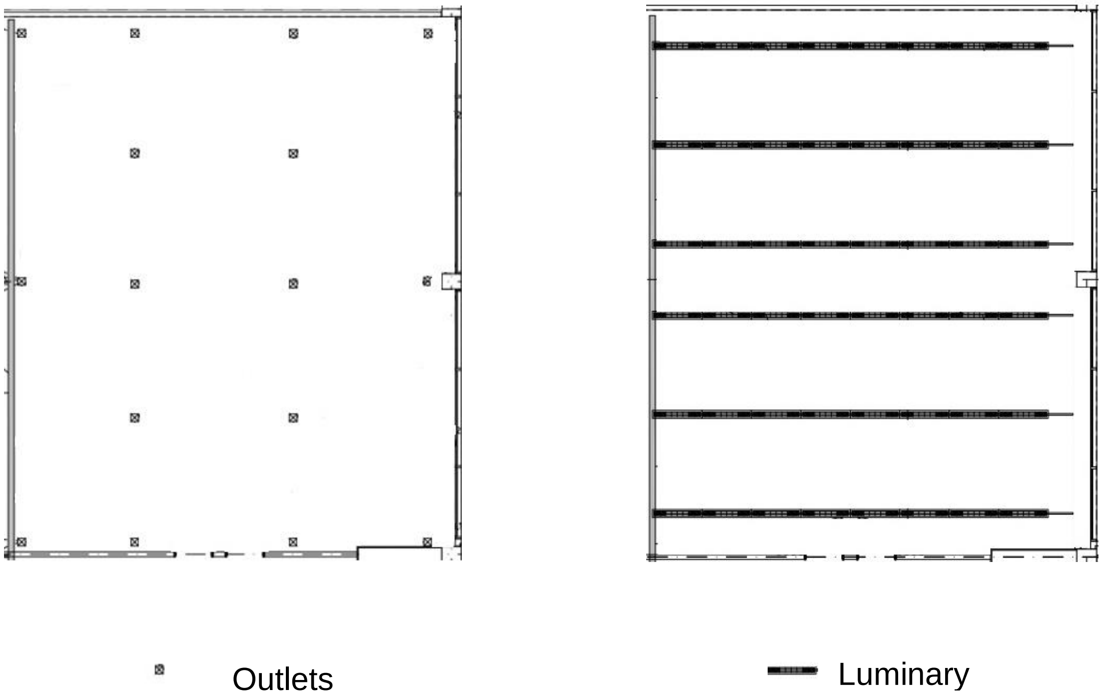
According to the planning tools of the physical arrangement, there are some steps in the physical arrangement planning that must be completed to establish the physical arrangement, such as determining the required area for each cell, the development of the interconnections diagram between spaces, adjustments in the diagram, to finally get to the detailed physical arrangement. However, for this task, it was decided not to perform these steps in planning the physical arrangement for the following reasons:

- The available area for the New Project Room is nearly 168m². In the interview with Professor Eduardo de Senzi Zancul, he told his expectations that each cell comprises six people comfortably. Only for reference calculation, it is assumed that all cells have the same area; therefore, the available area for each of the five cells exceeds 30m², an area more than sufficient to allocate all the necessary elements for each cell and the six people suggested by Professor Eduardo de Senzi Zancul. The calculation of the required area for each cell would be more relevant if the available area was smaller. In this case, it would be done calculations for each cell because if the required area surpass the available area, it would be necessary to review the size of cells to the reduced area required.
- *A priori,* the definition of the exact amount of each element and the relative positions of elements in each cell would create unnecessary restrictions into the New Project Room. As it is expected that the Project Room is a flexible, creative and innovative space, setting the arrangement of each cell individually apart from the whole Project Room excludes the possible interactions that may exist between the physical arrangements of the different cells. Moreover, as the available area is considerably larger than that actually required, it is possible to insert elements that were not predicted in the free spaces.
- The amount of element which must be arranged in the New Project Room is relatively low. The difficulty level of proposing a physical arrangement without the rest of the steps is not high, since the ideas and opinions proposed by Professor Eduardo de Senzi Zancul have become available to the dissertation, the reference situations analyzed, proposed physical arrangements of furniture that exist in the Steelcase company website and the experience of the dissertation's author.
- For furniture, which is the element that occupies a larger area of New Project Room, there is a wide range of alternatives available. For example, in different cells and different alternatives, tables of different shapes and different sizes may be more appropriate. The definition of furniture with the allocation of these throughout the development of alternatives allows to choose the most appropriate furniture for each situation.

With the decision not to use the rest of the steps of physical arrangement planning, it is possible to move on to the physical arrangement drafting.

Through blueprints of outlets distribution and lighting of the new PRO building, it appears that there is a wide distribution not only of outlets but also of lighting, allowing any element to be distributed throughout the area available, since the elements that have electric power requirements to operate will have source available, and that all parts of the room will be adequately lit.

Figure 24-Distribution outlets and luminary in the New Project Room



Source: executive design of the new building project of PRO

As suggested by Professor Eduardo de Senzi Zancul, in the proposed physical arrangements, the furniture of the Steelcase Company will be used. Steelcase is a company specialized in the production of office furniture for innovative, high quality and ergonomic designs. It produces a line of products designed exclusively for educational purposes, which also helps in student learning, allowing them to interact and carry out projects. Steelcase products can be purchased in Brazil through the authorized dealer in the country, Steelcase Furniture Trade Ltda., Located at Presidente Juscelino Kubitschek Avenue, n. 1600, block 122, Vila Nova Conceição, São Paulo city, state of São Paulo, 04543-000, +55 11 5102 4495. (Steelcase, 2013)

Although the furniture from Steelcase is recommended, it is not mandatory that the furniture must be purchased from this supplier. It was indicated because of its reputation of producing furniture with quality and ergonomics. When implementing the New Project Room, if the company chosen to purchase furniture is not Steelcase, or if any of the furniture chosen is no longer available, it is possible to make substitutions. To prevent this risk, the dimensions of each chosen furniture will be specified, so that it is possible to look for similar furniture.

As previously mentioned, elements that are directly linked to the development of projects in the room are already defined in specifications and quantity. For example: ergonomic analysis equipment, image processing equipment and 3D printers.

About the computers, its technical specifications are already set; however, it is necessary to define the amount needed. In regard to the furniture (tables, chairs, cabinets, TVs, sofas and whiteboards) there is still no definition, either of specification or of quantity.

Although the cost to purchase the elements is relevant to the project, in the interview with Professor Eduardo de Senzi Zancul, he stressed that there is no need to worry about this variable in the generation of alternatives, as there is available budget and, if necessary, the project could require more funds.

Three different proposals of physical arrangement will be prepared. Each one will be presented to Professor Eduardo de Senzi Zancul, so he can evaluate them, choosing one of the alternatives as a solution to the physical arrangement of the New Project Room, and then proposing improvements or modifications to any of the alternatives, creating and selecting a new alternative as a solution.

In all alternatives it was preferred not to use additional walls to the existing ones. In the interview with Professor Eduardo de Senzi Zancul, he demonstrated that the physical arrangement of the current Project Room, with walls separating the meeting rooms was not the best possible, because the change of physical arrangement would became more complex if necessary. Without the use of walls, furniture will be used (such as cabinets and whiteboards) to separate different environments when needed. Besides keeping the room more flexible for projects in the long run, not using walls allows greater interaction among its users.

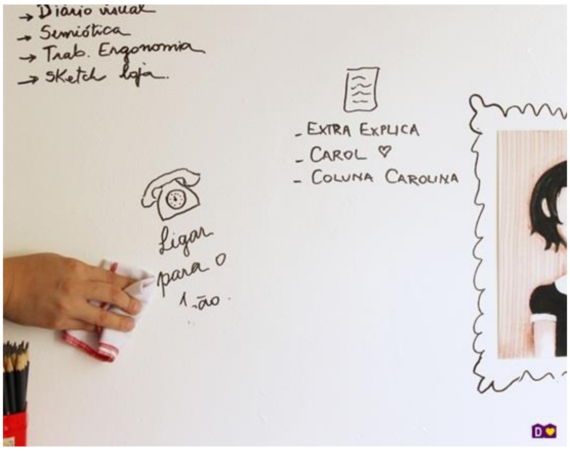
In all alternatives there will be at least an ergonomics cell, an image processing cell, a computer cell and two group meeting cells, as suggested by Professor Eduardo de Senzi Zancul. However, there may be more cells or other spaces that are none of the described cells, depending on the available space and the convenience to add it.

The monitors' suggestions will also be taken into consideration: bins will be distributed properly to facilitate the disposal of materials, there will be supports for the PLA rolls next to each 3D printers, 3D printers will be placed in a higher position than the current so that it is easier to observe the 3D printing piece, there is also an exhibition space for printed pieces in the closets.

While developing the chart of preferred interconnections, the door showed negligible preferred interconnections with all elements of the Project Room, since no element itself needs to be positioned next to the door. However, when analyzing cells, it is desirable that the door is closest to cells where there is more movement of people, such as the coffee area, and that it is far from more reserved areas where there are group activities, such as the cells of ergonomics, image processing cell and group meeting cells.

As noted in the Design Loft, in one of its walls there are areas that are totally taken by whiteboards surfaces, providing an ample space for notes. To make walls in which one can use whiteboard pens, it is suggested that all the walls of the Project Room to be covered by a material called vinyl adhesive, in white color, found in shops of material for screen printing. The vinyl adhesive turns the wall into a whiteboard on which one can write with whiteboard pens. (Dcoração 2013) As in some cases cabinets will be used to separate cells, it is recommended to apply vinyl sticker on the back of these cabinets, so that the cell that is not in the front of the cabinet facing the user of the cell has a whiteboard as well.

Figure 25-Example application of vinyl adhesive on a wall



Source: Dcoração (2013)

To illustrate the alternatives, the free software SketchUp (Trimble Navigation Limited, 2013) was used. SketchUp is a tool widely used by professionals and amateurs in the development of 3D engineering projects, design and architecture. It was chosen because, besides allowing easy editing and creation, allows downloading ready models of its models' database. These models are the projects of other users who have used the software and decided to share their models freely.

The Steelcase Company offers their SketchUp 3D models of furniture, so all furniture models (tables, chairs, sofas, cabinets and whiteboards are models of furniture from Steelcase Company, allowing the perfect representation of the furniture in style. To represent other elements such as computers, 3D printers, TVs, ergonomic analysis and image processing equipment, bins and coffee machine, generic models available in the models' database were be used. Though the models of some of these elements have been already defined, it could not be found ready models of these elements; however, as the area used by them is irrelevant when compared to the area of furniture, it will not bring insurmountable problems to the project.

In the group meeting cell, TVs were positioned at a lower height, because users usually will be in seated position; in the ergonomics cell and image processing cell, TVs were positioned at a higher height, because its users can perform activities sitting or standing, but usually in a standing position.

In all the alternatives there was available area for a coffee-break room.

The SketchUp software allows videos of 3D models created with the chosen views to be downloaded. It was possible to generate videos that simulate the vision of a person located in each cell of the New Project Room. So, videos for each of the alternatives were generated and uploaded to the website YouTube, to be more easily available to Professor Eduardo de Senzi Zancul and so they could be watched by all interested parties.

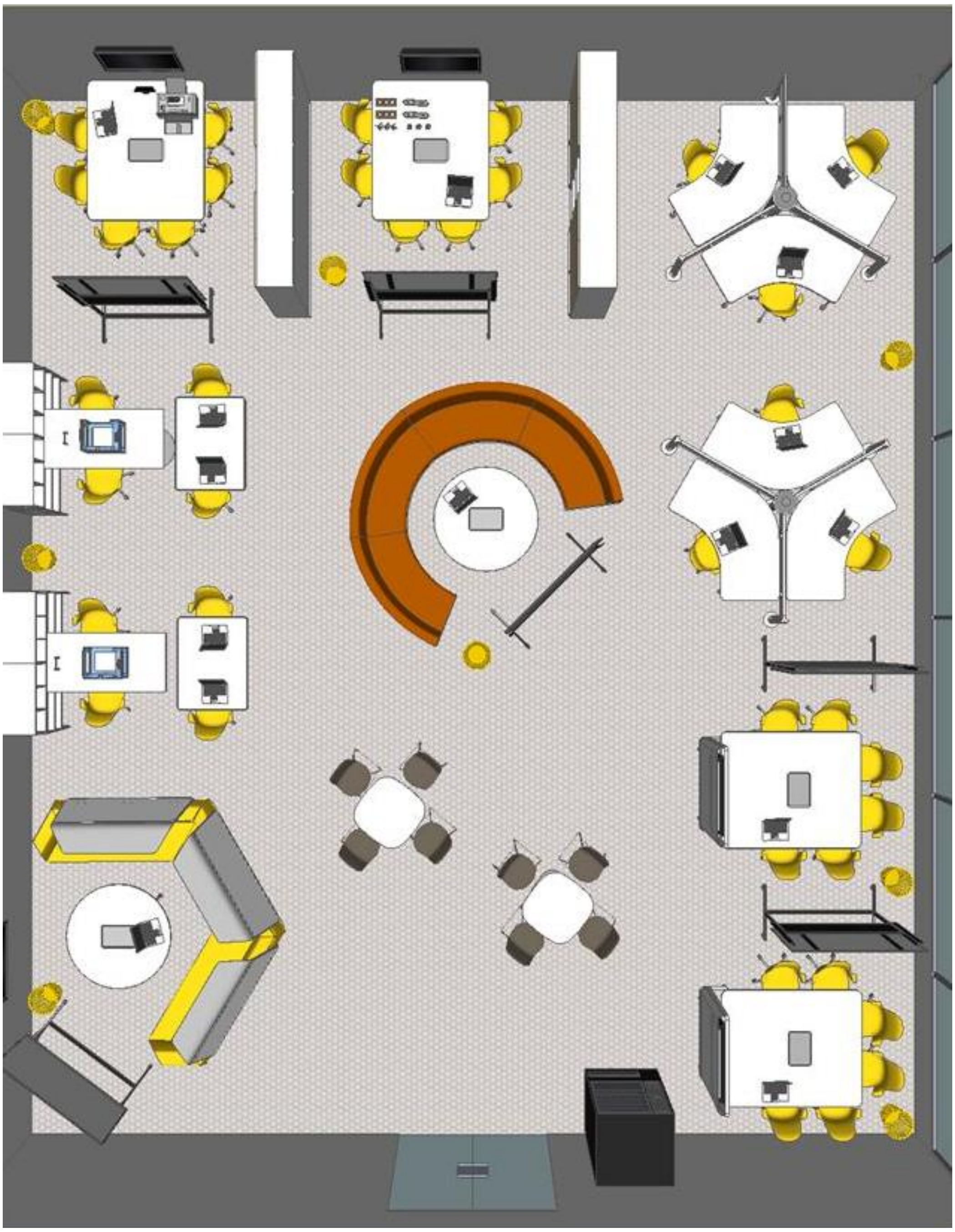
4.5.1 Alternative X

Table 17-Alternative X

Alternative	X
Link to the video on YouTube	http://youtu.be/liyvvs8gg88
People sitting in the cafe area	8
People sitting in cells computer	14
People sitting in the cell group meeting	20
People sitting in cells ergonomics	6
People sitting in the cell image processing	6
Computers	16
3D printers	2
TVs	5
Whiteboards	6
Cabinets	2
Bins	8

Source: prepared by the author

Figure 26-Alternative X



Source: prepared by the author

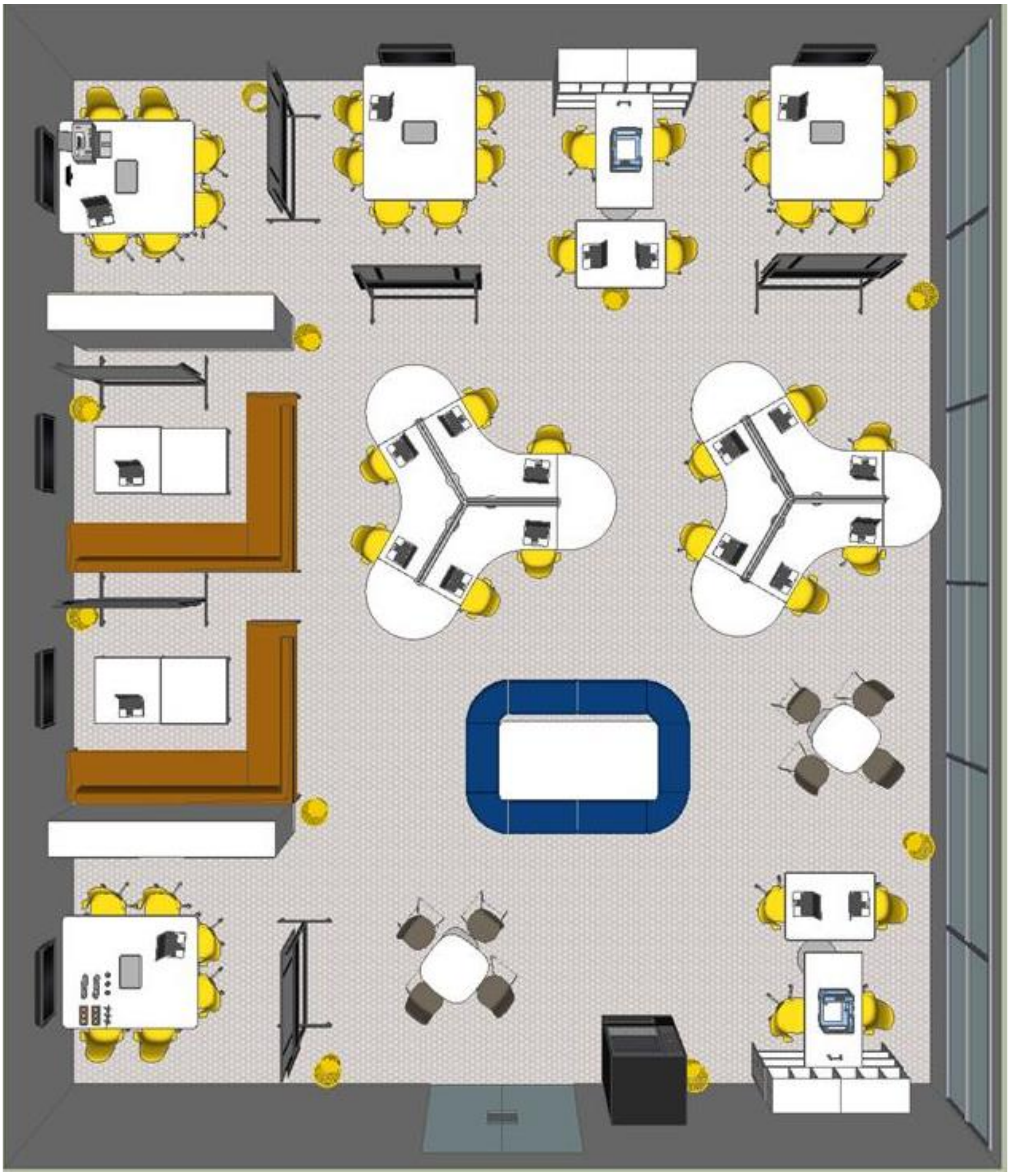
4.5.2 Alternative Y

Table 18-Alternative Y

Alternative	Y
Link to the video on YouTube	http://youtu.be/rb0aVGJWY4s
People sitting in the cafe area	18
People sitting in cells computer	20
People sitting in the cell group meeting	24
People sitting in cells ergonomics	6
People sitting in the cell image processing	6
Computers	22
3D printers	2
TVs	6
Whiteboards	6
Cabinets	2
Bins	10

Source: prepared by the author

Figure 27-Alternative Y



Source: prepared by the author

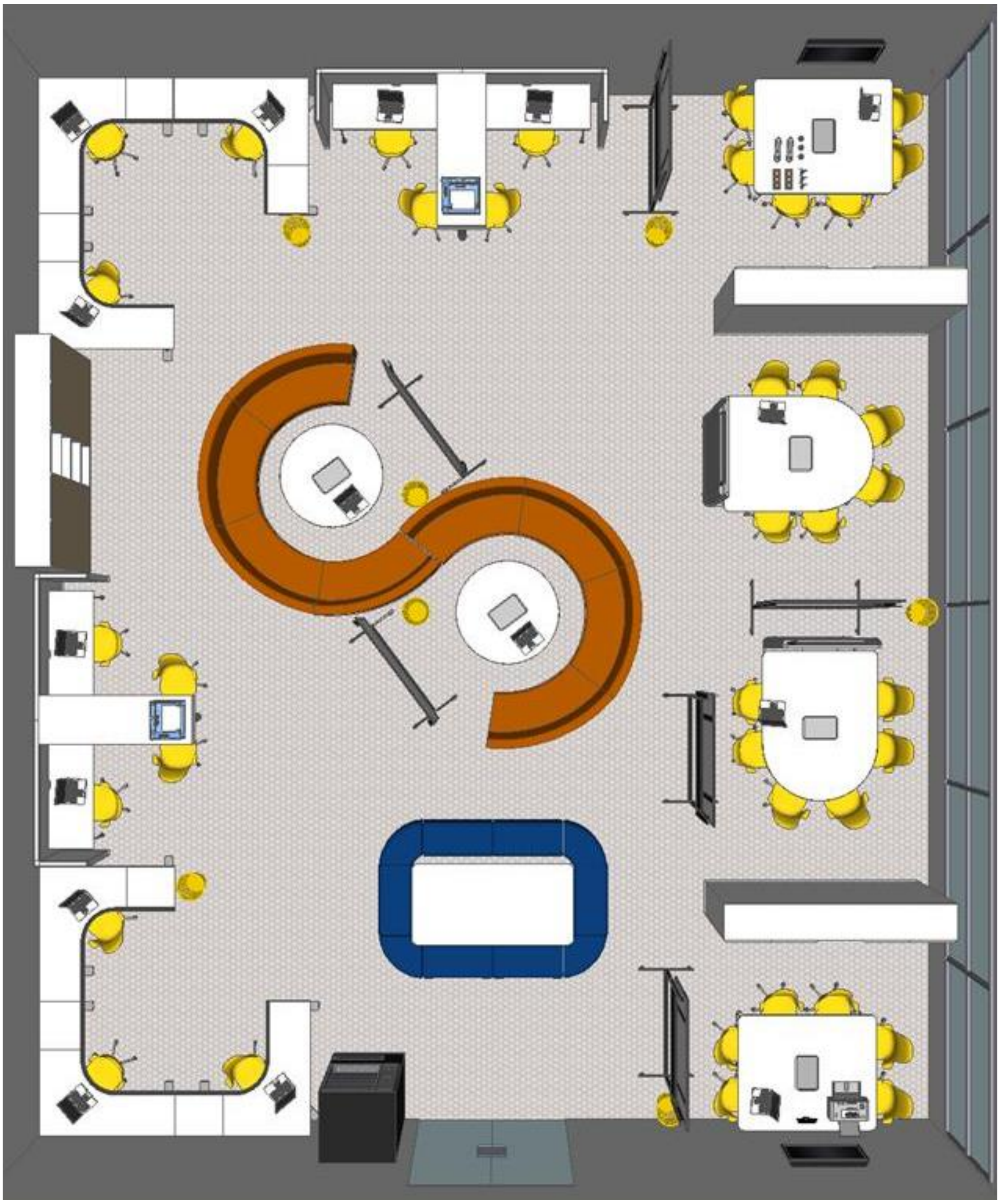
4.5.3 Alternative Z

Table 19-Alternative Z

Alternative	Z
Link to the video on YouTube	http://youtu.be/letwuZnckkM
People sitting in the cafe area	10
People sitting in cells computer	10
People sitting in the cell group meeting	28
People sitting in cells ergonomics	6
People sitting in the cell image processing	6
Computers	14
3D printers	2
TVs	4
Whiteboards	6
Cabinets	3
Bins	7

Source: prepared by the author

Figure 28-Alternative Z



Source: prepared by the author

4.6 Situation chosen

The relevant differences between the three alternatives concern on the position of cells within the available area in the Project Room and on the furniture used in each cell, which consequently modifies the capacity of each alternative.

Since all three alternatives meet all the objectives and requirements of the Project Room, regarding the presence of elements, interconnections between them and the expectations of Professor Eduardo de Senzi Zancul, the opportunity to choose the solution was given to Professor Eduardo of Senzi Zancul, since it is essential that he is in accordance with the final physical arrangement, so that it can be implemented in the future.

To select the final solution to the physical arrangement of the New Project Room, the three alternatives were presented to Professor Eduardo de Senzi Zancul through project blueprints and YouTube videos available on the site.

Table 20-Comparison between alternatives

Alternative	**X**	**Y**	**Z**
People sitting in the cafe area	8	18	10
People sitting in cells computer	14	20	10
People sitting in the cell group meeting	20	24	28
People sitting in cells ergonomics	6	6	6
People sitting in the cell image processing	6	6	6
Computers	16	22	14
3D printers	2	2	2
TVs	5	6	4
Whiteboards	6	6	6
Cabinets	2	2	3
Bins	8	10	7

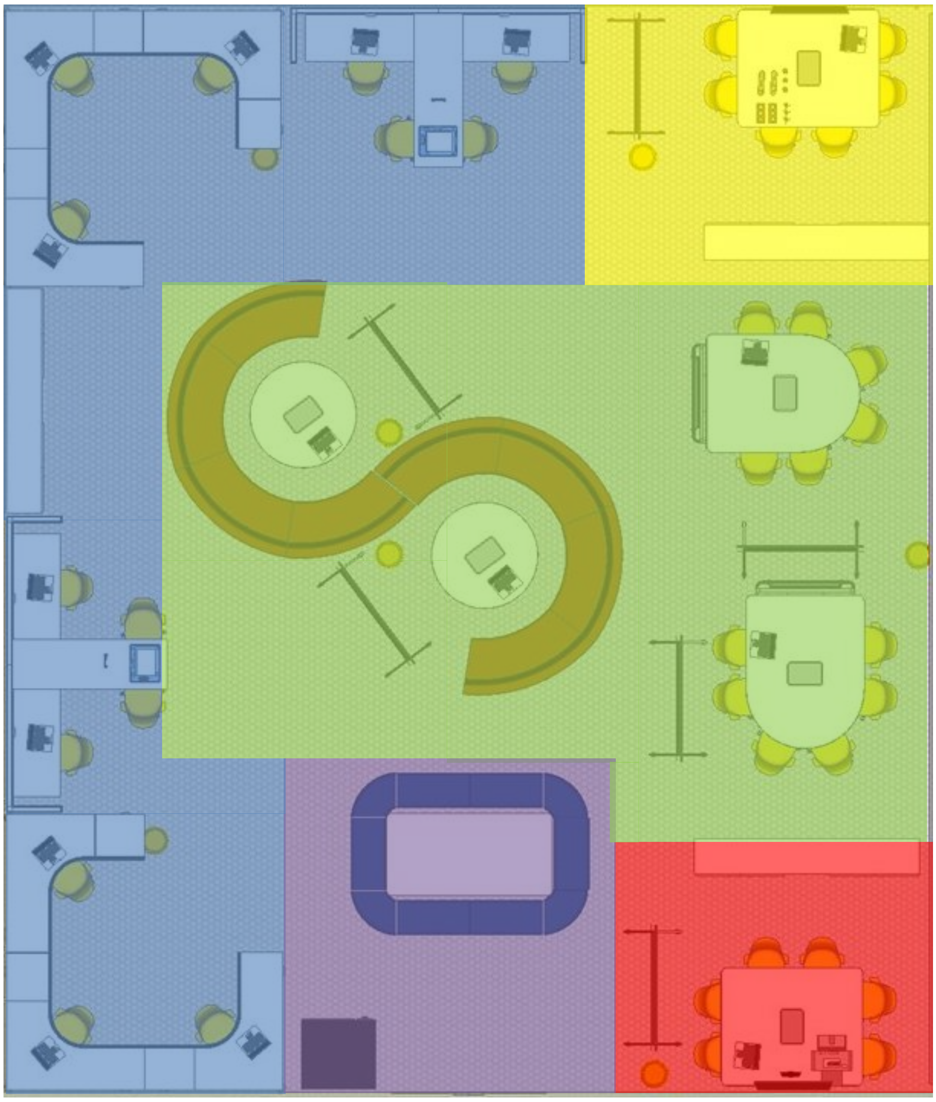
Source: prepared by the author

After analyzing the alternatives, Professor Eduardo de Senzi Zancul was briefly in doubt between X and Z alternatives, finally deciding for the alternative Z.

4.7 Solution description

With the choice of alternative Z as solution to the physical arrangement of the New Project Room, it becomes possible to describe in detail the chosen solution.

Figure 29-Division of cells



Computer cells

Image processing cell

Group meeting cells

Coffee-break area

Ergonomics cell

Source: prepared by the author

4.7.1 Computer cells

There are two types of computer cells in the solution, one type composed of two computers and a 3D printer, and other one composed of three computers.

In the type consisting of two computers and a 3D printer, both computers are connected to the 3D printer, the 3D printer is located in a slightly elevated position, allowing up to two users sitting to observe the 3D printing ensuring that, in the case any unexpected situation, at least one of the users can identify it and make the necessary adjustments. There is also the cabinet, used to store tools and materials for the operation of the 3D printer, such as the PLA (raw material), the pliers and the materials for cleaning the 3D printer.

In the type consisting of three computers, the tables are positioned to facilitate interaction between users, since they are practically side by side.

Figure 30-Computer cells

Source: prepared by the author

4.7.2 Group meeting cells

There are two types of group meeting cells, a type consisting of a table, a TV, a computer and six chairs, and a type consisting of a table, a computer, a whiteboard and a sofa for eight people.

In the type that has six chairs, the TV can be used to project what is being viewed on the computer, facilitating the visualization for all users.

The type that has sofas, the space is a bit more informal, the table is only a support, and it is not advisable to it use for long sessions in which one uses the computer or take notes, since the available resources are not adequate for these activities. It would be recommended the use of this type of group meeting cell for ideation, brainstorming and discussion sessions in which an informal and comfortable space is conducive to achieve better results.

Figure 31-Group meeting cells

Source: prepared by the author

4.7.3 Ergonomics cell and Image processing cell

In ergonomics cells and image processing cells, there is a table, six chairs, a computer, a TV, a whiteboard and a cabinet. In addition, there are also elements for ergonomic analysis and the necessary image processing devices.

The TV can be used to project what is being viewed on the computer and in the closet it can be stored all the equipment for ergonomic analysis or image processing.

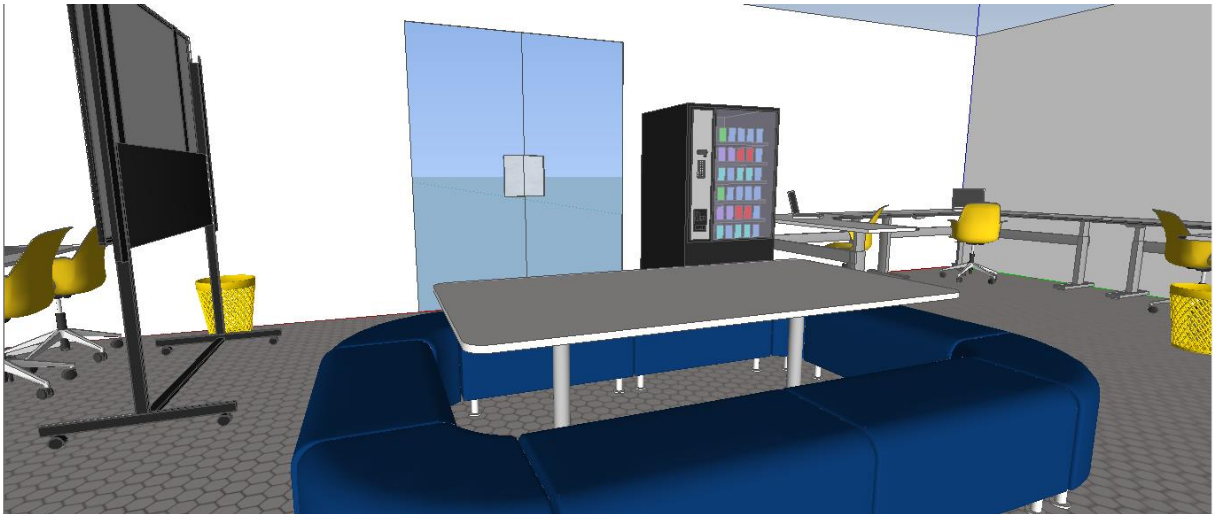
Figure 32-Ergonomics cell and Image processing cell

Source: prepared by the author

4.7.4 Coffee-break area

The coffee-break area consists of a table, puffs for ten people and a coffee machine. As there is the demand to make the New Project Room open 24 hours a day, it is interesting create a place where users could make a quick snack and drink coffee, since that in the cells the consumption of food or beverages will not be allowed.

Figure 33-Coffee-break area



Source: prepared by the author

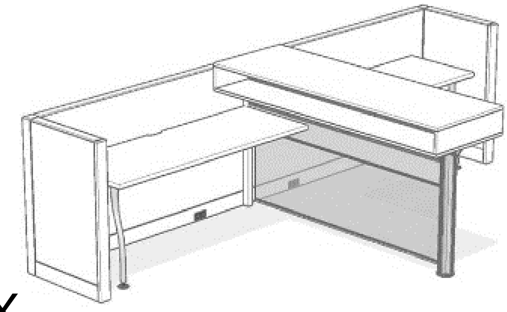
4.8 Specifications and the quantity of elements

As previously mentioned, it is objective of this dissertation to set the number of computers needed in the New Project Room, the furniture specifications and the quantity of furniture required.

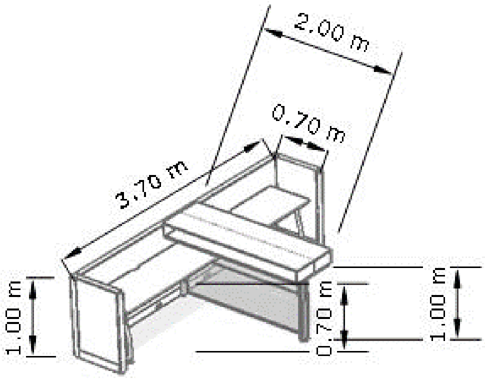
In the solution chosen, computers with high processing capacity are needed for the image processing cell and thirteen computers with lower capacity can be set for the other cells, as shown in the 3D model.

In the model, only furniture from Steelcase Company was used. On the following tables, the specifications and required quantities of each mobile are presented. In some cases the furniture is assembled from prefabricated parts, then, all the parts will be described. The descriptions were taken from the catalog in English. (Steelcase, 2013)

Table 21-Quantities and specifications



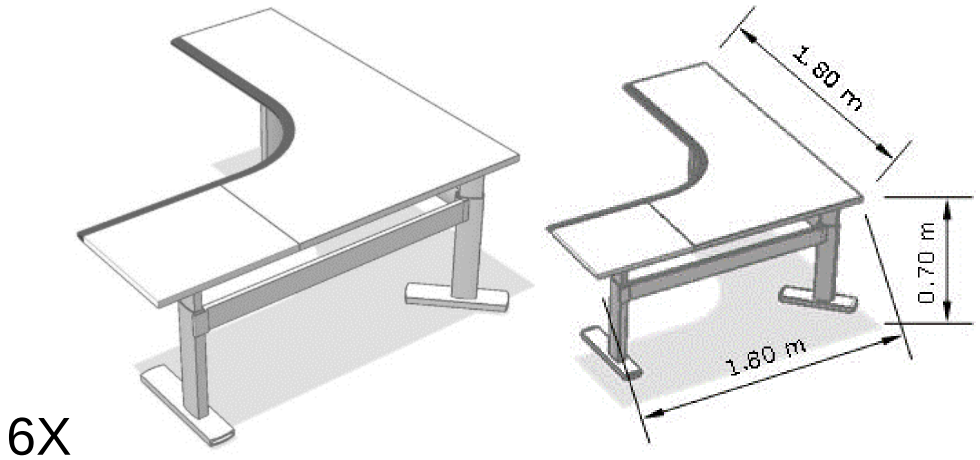
2X



Quantity	Code	Name
2	BB072	Beam-6 Feet W
2	BDS78PB	Duo-Slim, Post & Beam Application, 26x7-1/2x78
2	BIBMD066	In-Fill-Desk Height, Fence to Floor, 5-1/2w
2	BXP36	Post-X, Base, 33h
2	BXPTC	Top Cap-X Post
2	CFENCELC	Connector-Fence, Left Hand, Technology Wall
8	BCAB	Cabby Leg-Glide, 28 1/2"H
4	TS71SSX	Receptacle-System Ground, Line1, 3+1
4	TS72SSX	Receptacle-System Ground, Line 2, 3+1
4	TS74224STF	Panel-Full Tackable Acoustical, Square, 42x24
4	TS74272STF	Panel-Full Tackable Acoustical, Square, 42x72
4	TS742SEPJ	Junction-End of Run, Square, 42h
2	TS742SIPJ	Junction-Inline, Square, 42h
4	TS742SLPJ	Junction-L, Square, 42h
2	TS76BPX	Power In Feed-3+1, 6 Feet
4	TS7PK72X	Power Kit-3+1, 72w
4	TS7WKSPT	Reinforcing Channel-60/72 Application
4	US2466	Worksurface-Straight, 24x66

Source: Adapted from Steelcase (2013)

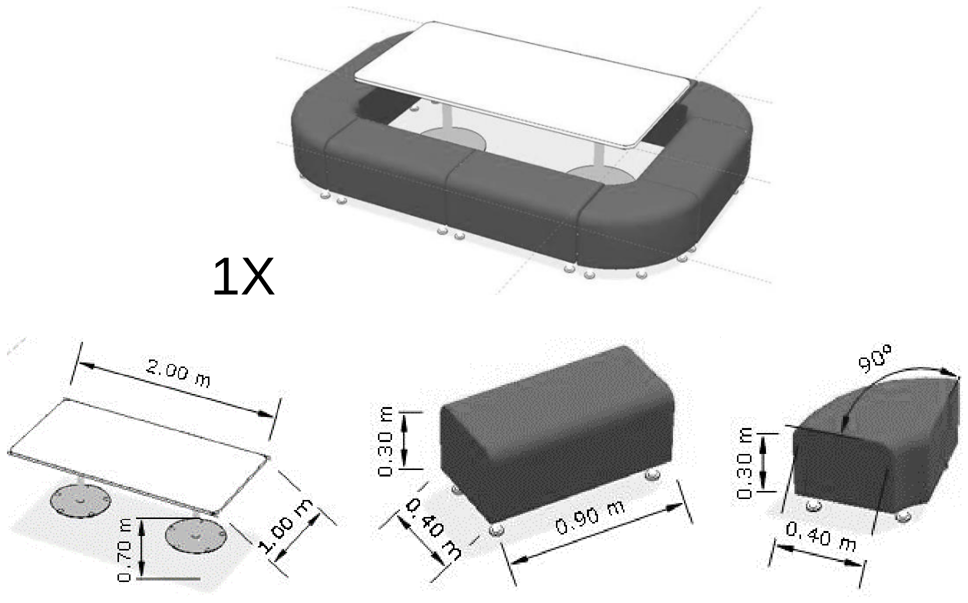
Table 22- Quantities and specifications



Quantity	Code	Name
6	A7LQ70237023S	Series 7-90 Degree, 70x23x70x23, Urethane Profile Adjustable Height

Source: Adapted from Steelcase (2013)

Table 23- Quantities and specifications

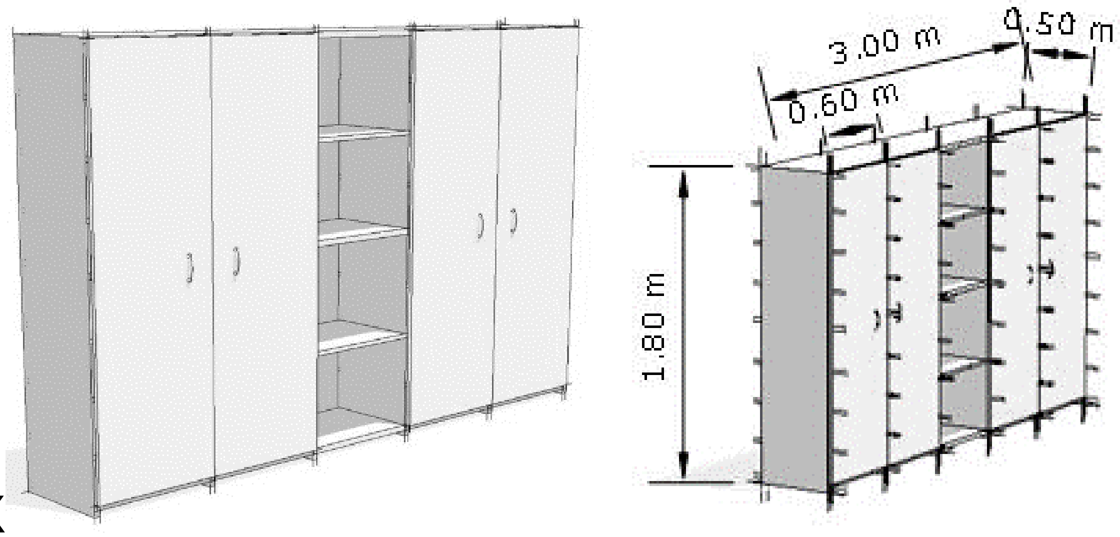


Quantity	Code	Name
2	TS4TBASE28	Base-28" Diameter
2	TS4TLR4242	Top-Square Table, Low Pressure Laminate, 42x42
4	TS34402	Ottoman-Alight, Corner
6	TS34403	Ottoman-Alight, Bench

Source: Adapted from Steelcase (2013)

Table 24-Quantities and specifications

3X

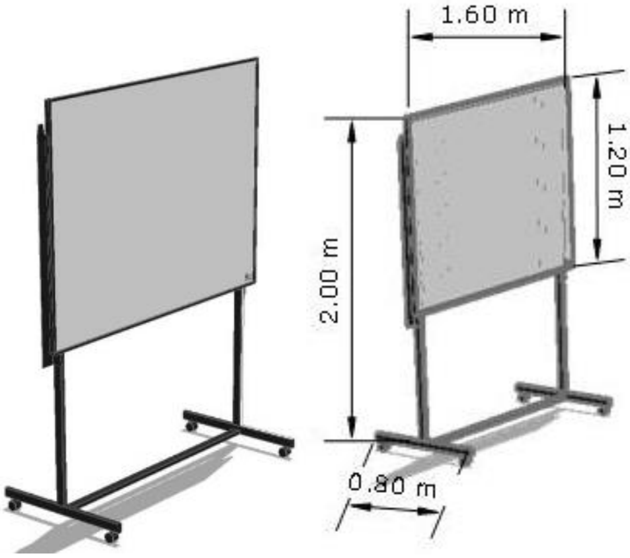


Quantity	Code	Name
3	TS5TLCBW725	Workwall-Bookcase, Closed Back, 118 1/2”Wx72”H
12	TS5TLDWW72	Workwall-Door, 72”H

Source: Adapted from Steelcase (2013)

Table 25-Quantities and specifications

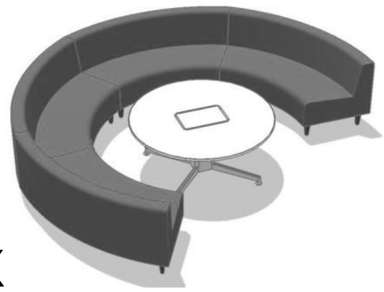
6X



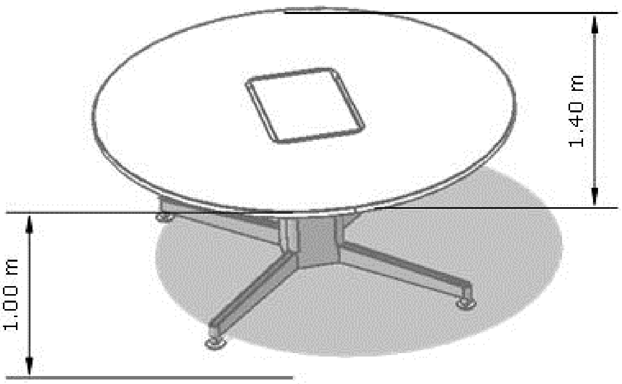
Quantity	Code	Name
6	ENO2610A	Eno; Whiteboard, Interactive, Pattern A, 48Hx63W

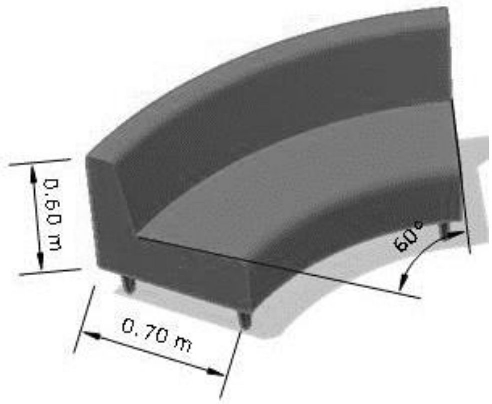
Source: Adapted from Steelcase (2013)

Table 26-Quantities and specifications



2X

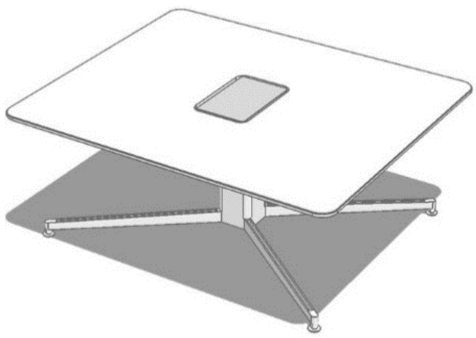




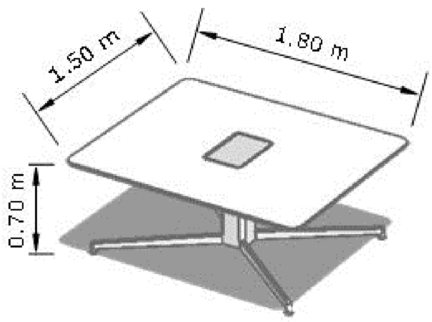
Quantity	Code	Name
8	451-7460FI	Chair-Circa, Modular, 60 Degree, Inside Facing Wedge Loveseat, 5 Legs
2	MTLR54	Table-Lounge Height, Round, 54

Source: Adapted from Steelcase (2013)

Table 27-Quantities and specifications



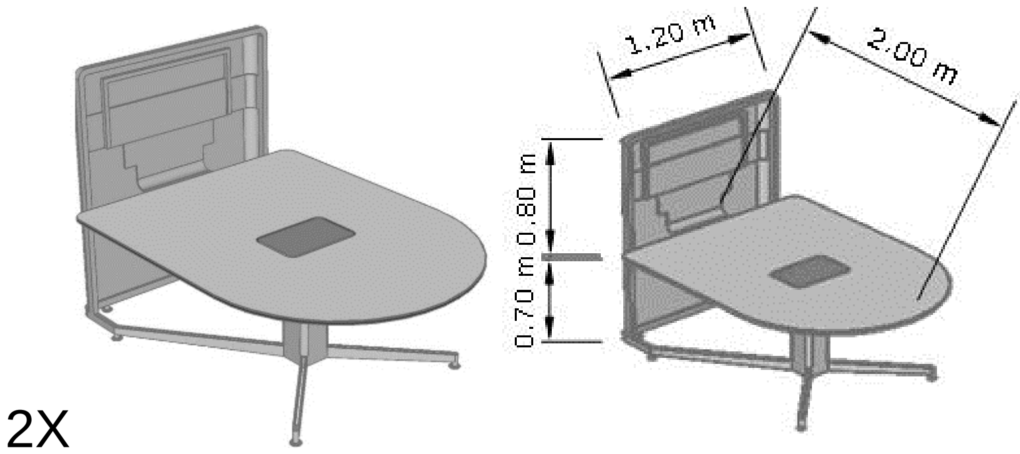
2X



Quantity	Code	Name
2	MTDR7260	Table-Desk height, Rectangle, 72Dx60W

Source: Adapted from Steelcase (2013)

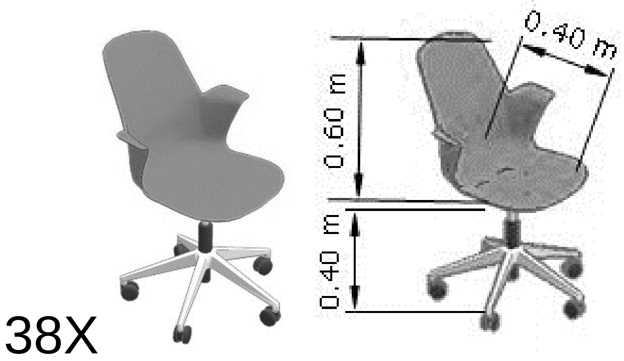
Table 28-Quantities and specifications



Quantity	Code	Name
2	MTDL7860T	Table-Desk height, Large D shaped, Attached totem, 78Dx60W

Source: Adapted from Steelcase (2013)

Table 29-Quantities and specifications



Quantity	Code	Name
38	480130	Node; Chair, 5 arm base

Source: Adapted from Steelcase (2013)

With the specifications of the furniture, it becomes possible, while implementing the New Project Room, to purchase other furniture pieces that are similar to those used in the 3D model, if it is not possible to purchase the furniture herein specified, whether the decision is not to use the Steelcase company as a supplier or if the production of some pieces of furniture are terminated.

5 CONCLUSION

The objective of this work was the physical arrangement planning of the New Project Room. In this dissertation, it was possible to integrate the knowledge of two disciplines of Production Engineering: physical arrangement planning and ergonomics.

The decision of the physical arrangement is a step through which every organization must undergo at some point, and its importance to the organization may be higher or lower, varying from organization to organization. In the New Project Room the importance of the physical arrangement planning was to set the amount of computers, the quantity and specification of furniture that must be purchased for the New Project Room. Moreover, by the time that the physical arrangement of the elements will actually be placed in the New Project Room, the 3D model generated will enable the allocation of elements in the planned and desired positions.

For the physical arrangement planning, the tools and methodology of physical arrangement planning were useful as the basis to design a project that could meet the New Project Room objectives within its restrictions. The tools and methodology of ergonomics were useful as support in the physical arrangement planning of the New Project Room, providing information necessary for a more complete physical arrangement planning development.

The next steps that follow the development of this dissertation are purchasing all the elements required for the final implementation of the New Project Room in the new PRO building, as soon as it is built. In the implementation, it will be necessary elements from the 3D model generated, as stipulated in this dissertation. Over the years, it is possible that the physical arrangement defined above does not work in further future needs, however, the existing flexibility in the New Project Room (no additional walls were planned, there is lighting and outlets distributed throughout the area, furniture are not immovable) allows this physical arrangement to be easily changed according to these needs.

The steps followed in this dissertation can also be used in the physical arrangement planning of Prototypes Center of the new PRO building which, as well as the New Project Room, will integrate the InovaLab@POLI.

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