Simulation and sizing of a photovoltaic module manufacturing plant

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Abstract. The search for alternative energy sources, motivated by the need for new energy matrices, has resulted in strong technological advances, aiming at the use of renewable resources with the aim of providing sustainability and saving natural resources. The objective of this project is inserted in this context, seeking to analyze in a sustainable way a simulation and dimensioning of a photovoltaic module manufacturing plant. In this way, each step related to the module's production process will be developed and explained, from the flow of materials, interconnection diagrams per line and diagram per block. Additionally, develop the floor plan and 3D sketch of the manufacturing area. The results were satisfactory, after the simulations the manufacturing plant met the daily production requirements, producing a total of 720 units/day. For transport and electrical energy costs, high data were obtained as it requires a high demand for energy to keep the production line running, but there are sustainable solutions to resolve this high expenditure on electrical energy and will be addressed throughout the study.

Keywords: Production Engineering, Photovoltaic Module, Sustainability

1. Introduction

Research into alternative energy sources, given environmental concerns and energy shortages, has been highlighted today. Inserted in this context is the justification for this research, with a specific focus on the simulation and sizing of a photovoltaic module manufacturing plant.

According to article (TIRADENTES, 2006), the greater the use of electrical energy using solar modules, the greater the preservation of the environment; People who use electrical energy from photovoltaics are avoiding the consumption of fossil fuels. Likewise, in a more advanced analysis, they are contributing to reducing the need for flooding caused by hydroelectric plants.

According to article (GHENSEV, 2018), there are increasing advances in alternative sources and solutions for the environment. As a result, photovoltaic systems are increasingly consolidated in the current market, whose main function is the conversion of solar energy into electricity in a clean and sustainable way. The intense exploitation of exhaustible fossil fuel reserves, and the damage caused to the environment, present a worrying scenario for the next century, justifying the search for alternative sources of electrical energy generation.

Based on the information above, a simulation and sizing of a photovoltaic module manufacturing plant will be proposed, driven by the need to produce energy-generating modules since the modules use a renewable resource source to generate electricity. This study aims to theoretically analyze a simulation using AUTOCAD software of a photovoltaic module manufacturing area, highlighting the entire production process, from the arrival of raw materials to the finished product. Furthermore, the floor plan and a 3D sketch of the photovoltaic module manufacturing company will be demonstrated.

2. Literature review

2.1 Benefits generated in the manufacture of photovoltaic modules

Photovoltaic systems can generate electricity in any space where a photovoltaic module can be installed. Electricity generation in urban areas stands out and photovoltaic plants can be built in open areas of any size, close to or far from consumption centers. The climatic and territorial conditions of our country are extremely favorable for photovoltaic solar energy. Book (BURIOL, 2022).

For Abinee articles (BIAGIO, 2021), photovoltaic systems connected to the grid in buildings can act in synergy with the distribution system, minimizing the load, such as that generated by air conditioning equipment in shopping centers. In urban centers, photovoltaic systems can be used in already occupied areas, residential roofs, parking lots and building roofs, such as distributed generation units.

From the point of view of book (VILALVA e GAZOLI, 2012), the use of this technology also helps to preserve the environment, as the energy generated by photovoltaic modules does not cause any environmental damage, so that the energy generated is 100% free of greenhouse gas emissions. (GHG). In addition to increasing the availability of electricity and the environmental benefits of using a renewable source, the insertion of photovoltaic solar energy in the country will boost technological development, create jobs and boost the national economy.

2.2 Photovoltaic cell used in the production of PV modules.

When two types of semiconductors are inserted into a PN junction and the carriers have opposite charges, the electrons move toward each other. They can cross the junction, depleting the region where they originated and transferring their charge to the new region. Through this effect, an electric field, called a gradient, will be produced, which quickly reaches equilibrium with the attractive force of the excess carriers. This field becomes a permanent part of the device. In this case, it forms a type of ramp in which the carriers tend to slide across the junction when they are close. BOOK, (VILALVA e GAZOLI, 2012).

The most commonly used semiconductor is silicon. Its atoms are characterized by having four electrons that bond with their neighbors, forming a crystalline network. When adding atoms with five bonding electrons, such as phosphorus, there will be an excess electron, which cannot be paired and which will be left over, weakly bonded to its original atom. ARTICLE [7]. See Fig. 1 shows the cross-section of a photovoltaic cell.

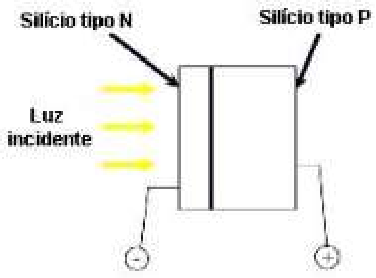


Fig.1. Cross section of a photovoltaic cell

For a clearer understanding of the functioning of the photovoltaic cell, (see Fig. 1) shows a cut-away model of a cell, exemplifying the incidence of solar rays on the surface and, from there, the movement of electrons migrating from one layer to another, generating a continuous flow of electrons.

According to article (CRESESB, 2014), when light shines on the photovoltaic cell, the photons that make up it collide with the electrons in the silicon structure, giving them energy and transforming them into conductors. Due to the electric field generated in the P-N junction, electrons are oriented and flow from the "P" shell to the "N" shell.

Using an external conductor, the negative layer is connected to the positive layer, thus generating a flow of electrons and an electric current in the connection. As long as light continues to shine on the cell, the flow of electrons will continue. The intensity of the current generated will vary proportionally according to the intensity of the incident light. (NASCIMENTO, 2021).

Currently, industries using this technology are using various materials and types of structures to produce photovoltaic cells. Silicon is still the most used input, thanks to the technological knowledge developed about this material and the ease with which it is available in nature. The best-known forms of semiconductors are monocrystalline, amorphous and polycrystalline silicon.

Polycrystalline silicon: Polycrystalline silicon cells are produced from silicon blocks obtained by melting pure silicon in special molds. Once in the molds, the silicon slowly cools and solidifies. In this process, the atoms are not organized into a single crystal. A polycrystalline structure is formed with separating surfaces between the crystals. Over the years, the manufacturing process has achieved maximum efficiency of 12.5% on industrial scales.

2.3 The photovoltaic module

According to the article [6], each photovoltaic module is made up of a certain number of cells connected in series. Based on physical principles, when the negative layer of one cell is joined to the positive layer of the next, electrons flow through the conductors from one cell to the other. This flow repeats until reaching the last cell of the module.

Typically, an isolated photovoltaic cell produces 1.5 W of power, with voltage and current respectively 0.5 V and 3 A. However, to increase the potential of a cell, associations must be made between the cells in such a way to form a photovoltaic module.
Complementing Nascimento's explanation [6], corresponding to the formation of photovoltaic modules, the assembly principle is characterized by the addition of individual cells connected in series, allowing voltages to be added. Generally, modules made up of 30, 32, 33 and 36 cells in series are produced, depending on the application and desired voltages.
The aim is to give the module rigidity in its structure, electrical insulation and resistance to climatic factors. Therefore, the cells connected in series are encapsulated in an elastic plastic Ethylvinylacetate-EVA, which also acts as an electrical insulator, a tempered glass with low iron content, on the side facing the sun, and a multilayer plastic sheet Polyester on the side later. In some cases the glass is replaced by a sheet of transparent plastic material.

3 Materials and methods

As already mentioned, this study aims to analyze the development of a photovoltaic module manufacturing plant using AUTOCAD software to support sizing and simulations. Obtaining results from the installation plant, transportation costs and energy costs, with the aim of determining the theoretical feasibility of the photovoltaic module manufacturing plant.
See Fig. 2 presents a sketch of the photovoltaic module to be produced. It basically consists of sheets composed of a layer of glass, EVA, photovoltaic cells, EVA and TEDLAR. The TEDLAR material has the function of providing rigidity for the rear part of the assembly, while the two EVA layers provide an encapsulant for the PV cells. And, the tempered glass protects the module from natural weather, such as hail, wind and possible dropped tools during installation. And for the module to be fully produced, it is framed with aluminum frames, known as a frame or FRAME.

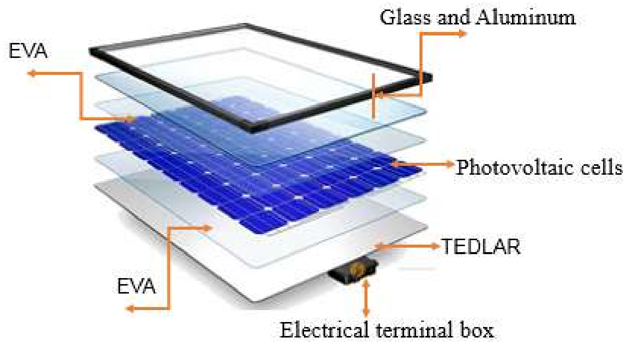


Fig. 2. Photovoltaic module on the production line

The photovoltaic cell technology to be used in this study to manufacture the photovoltaic module is polycrystalline cilice. This type of cell is widely used in the

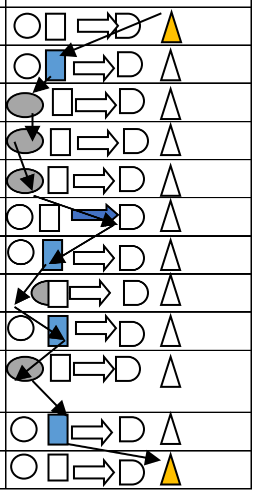
market and presents a satisfactory conversion efficiency, developing an adequate final power.
For simulation purposes in the AUTOCAD software, it was decided to consider the production of two types of photovoltaic modules, the first with a power equivalent to 450Wp and the second with 500Wp of final power. Remembering that you must program the module model you want to produce on the production line, that is, never mix the two types on the same manufacturing line.

3.1 Photovoltaic module manufacturing process flow

The production of photovoltaic modules must comply with each process level, from the arrival of raw materials, glass, EVA, photovoltaic cell, TEDLAR, welding inputs and inspection and packaging materials.
To this end, a process flow diagram containing each step of the photovoltaic module manufacturing line was developed in this study. Table 1 provides production flow.

Table. 1. Process Flow Diagram

Process: Assembling a photovoltaic module			
Product: MFV450W and MFV550W			
Nº	Activity description	Duration	Type of activity
1	Receipt of raw material	-------	
2	Sort and select	5min	
3	Cut into half cells	15min	
4	Weld electrode on each element	25min	
5	Get glass, eva, cell set and tpt	2min	
6	Take to lamination machine	10min	
7	Pass test I	2min	
8	Install aluminum frame	10min	
9	Pass test II	4min	
10	Install the junction box and connector cables	5min	
11	Inspect and pack	5min	
12	Store in batches	80 min	



Firstly, the raw material arrives at the warehouse, after release for production, a flow of material begins and the manufacturing process begins. Each activity is highlighted with signs to identify the operation to be performed. Where, triangle identifies the storage process, rectangle is characterized by inspection and testing. And, circles present the operation process of cell cutting, welding, lamination, framing and installation of electrical cables.

3.2 Relationship diagram

After knowing the process flow for the production of the photovoltaic module, it is necessary to establish communication between each sector. To this end, a relationship diagram containing the proximity of each sector is presented in (see Fig. 3).

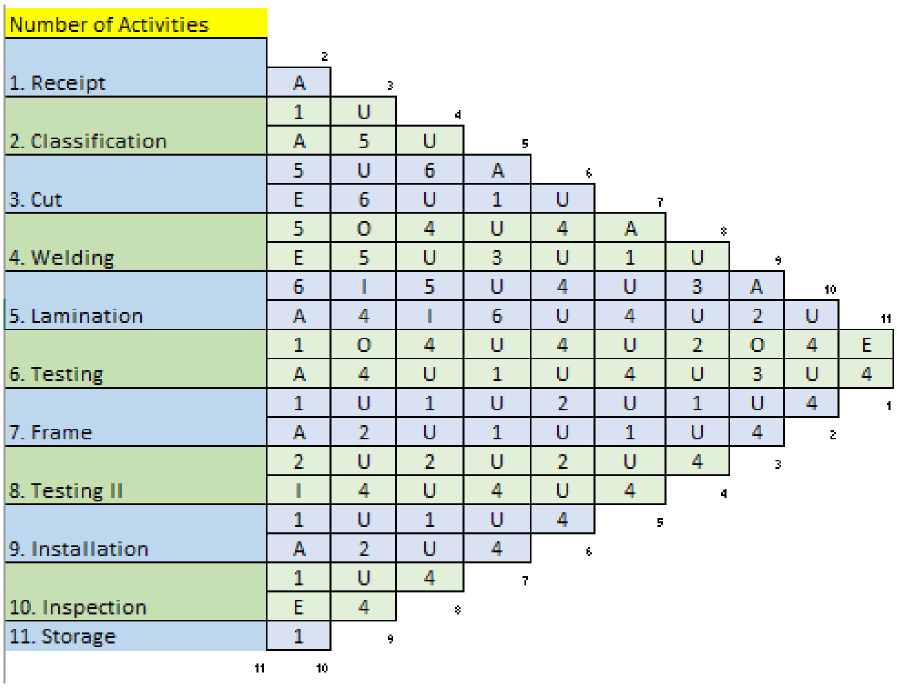


Fig. 3. Relationship diagram linked to the production of photovoltaic modules

The relationship diagram is extremely important to identify the affinity with each sector of the process flow. Each activity to be developed is essential to successfully manufacture the photovoltaic module, therefore the relationship diagram presents an appropriate sequence of activities to be carried out. The combination between codes [A and 1] presents an extremely important relationship, that is, these two sectors depend on each other. The codes [U and 6] are the opposite, as there is no need for the sectors to be interconnected.

Line interconnection diagram. The line diagram complements the relationship diagram, since both are correlated. In other words, the line diagram unifies each activity to be developed in the production of the module, considering the level of proximity between each sector. See Fig. 4 presents the proposed model of the photovoltaic module production line in a diagram per line.

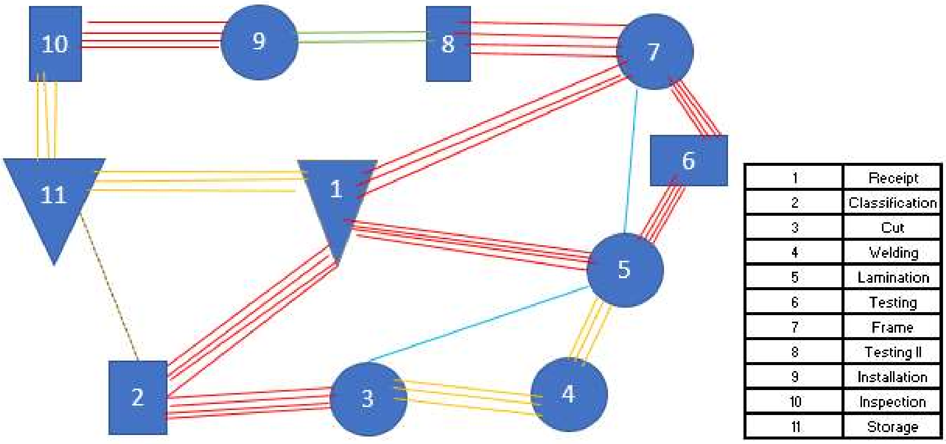


Fig.4. Diagrama de interligação por linha

It can be seen that each activity is represented by symbols characterized by the process flow, triangle, rectangle and circle, storage, testing and operation. Each number describes the types of activity per process and, in the correct sequence, for manufacturing the photovoltaic module. The process begins with receiving raw materials and ends with finished product stock.

Block interconnection diagram. Continuing with the methodology for manufacturing the photovoltaic module, we next have the dimensioning of the area by activity carried out, in this case, a survey of the nominal area is carried out according to the space occupied by machinery, storage and movement. See Fig. 5 shows the block interconnection diagram.

Department	
1	150m²
2	7m²
3	10m²
4	25m²
5	15m²
6	8m²
7	10m²
8	8m²
9	10m²
10	8m²
11	150m²

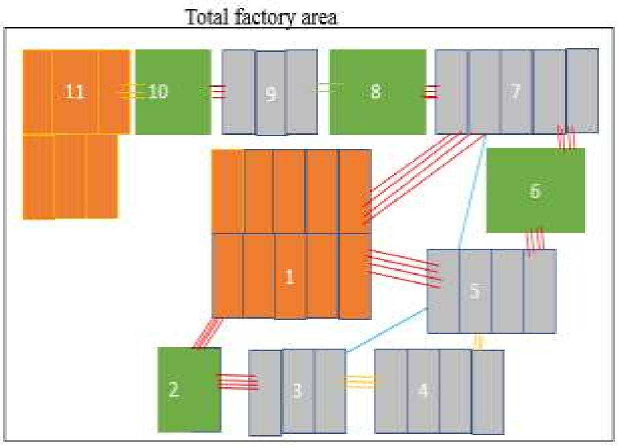


Fig. 5. Block interconnection diagram of the manufacturing area

Each sector of activity requires specific machinery to manufacture the photovoltaic module. According to the catalog of equipment and machinery for assembling modules book (TIRADENTES, 2006) presents the corresponding areas of each process and steps to be constructed, in this case, using these data from total area it is possible to draw up the block interconnection diagram shown in fig. 5.
At this stage, the scope of the factory is ready, with a description of the process flow, activities, list of each sector and data on the area needed for the photovoltaic module manufacturing plant.

4 Results and Discussions

By applying the methodology and following the stages of developing the construction of a photovoltaic module manufacturing plant, we reached the results.
To analyze the results and simulations, the AUTOCAD software was used, using which the entire floor plan was built, following the steps presented in the methodology. After the construction stage, transportation cost and energy cost simulations were carried out. As well as a 3D image representation of the entire manufacturing area. See Fig. 6 represents the sketch of the floor plan of the photovoltaic module factory.

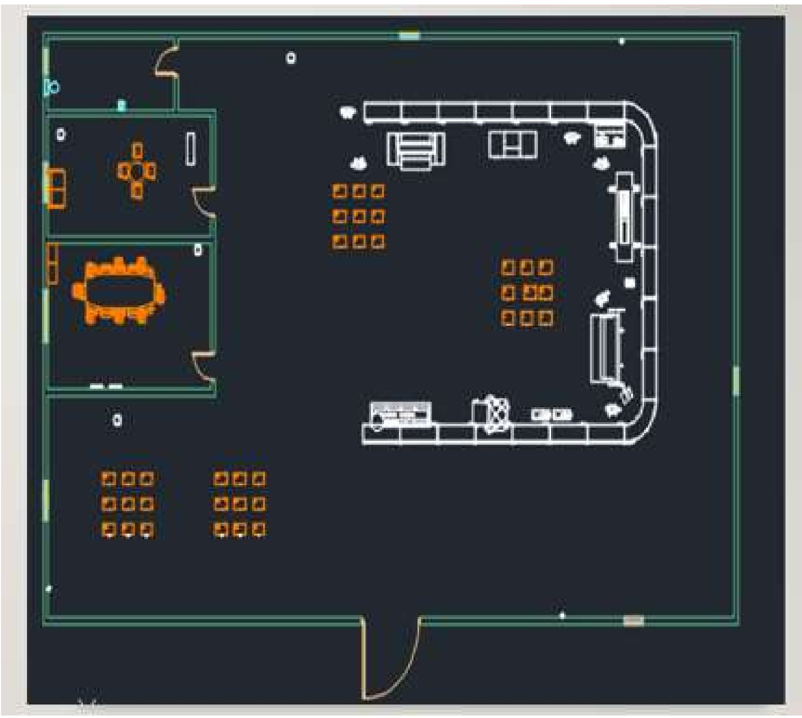


Fig. 6. Floor plan of the factory area

It can be seen that the plan has the area described by the block diagram, in addition, it has an additional area reserved for an office, an entertainment room for employees and a bathroom. Because it is a U-shaped layout, the process flow is continuous and follows the production line. There is no need for walls separating each sector, as we saw in the previous section, each activity is related. The main door is oriented on the side and is easily accessible for delivery of raw material, as well as dispatch of the finished product. As seen, the plant was designed with every detail in mind to maximize production performance, quality and employee well-being.

4.1 Transport cost analysis

After the construction and sizing of the manufacturing plant, a simulation of the transportation cost will be carried out applied to the photovoltaic module production process considering the 11 manufacturing stages.
See Fig. 7 represents the results of this transport cost simulation. The equipment used to carry out internal transport is by forklifts.

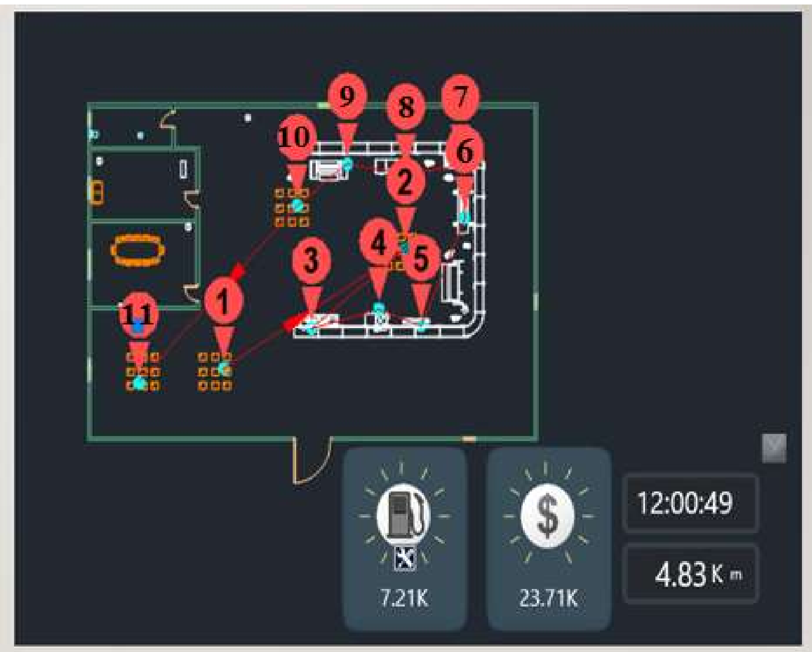


Fig. 7. Transport cost analysis

Based on the results of the transport cost, it can be seen that, to produce 360 photovoltaic modules in 12 hours, it is necessary to travel a distance of approximately 5 km within the industrial park, passing through the production stages, which is equivalent to spending approximately 7000 liters of fuel. Thinking about ensuring sustainable development, the solution to meeting this energy demand with transportation is the installation of electric forklifts, avoiding the consumption of fossil fuels. As it is a photovoltaic module factory, part of the module production can be allocated to start the installation of a photovoltaic system in the company and supply this energy consumption by forklifts.

4.2 Electricity cost analysis

All of the company's machinery requires a source of electrical energy to operate, therefore, after the energy cost simulation, the data obtained will be analyzed in detail. See Fig. 8 demonstrates the simulation data for energy cost.

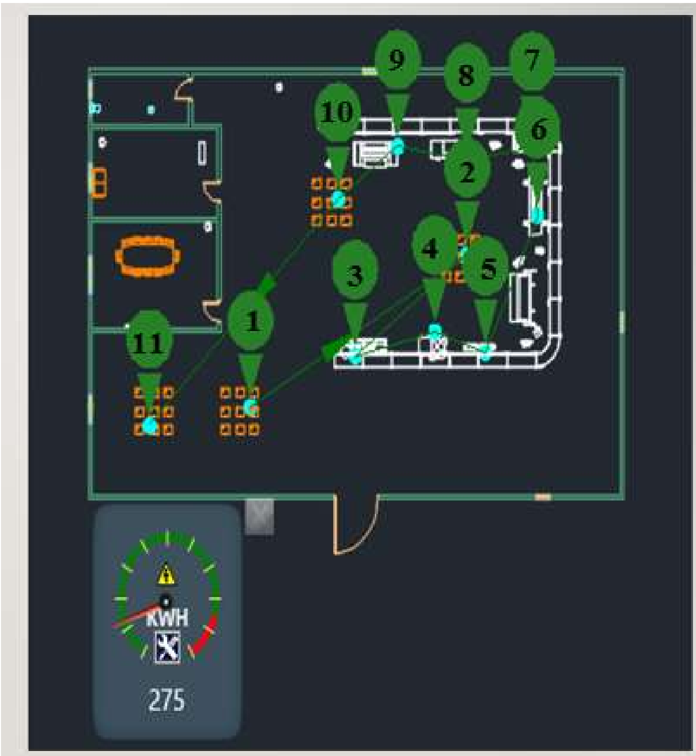


Fig. 8. Energy cost analysis (electrical energy)

As mentioned previously, equipment in general consumes electrical energy, therefore, daily electricity consumption varies around 275kWh. Remembering that the company assembles the photovoltaic module, that is, the photovoltaic cells are ready-made and supplied by partner companies that manufacture polycrystalline fiber cells. To meet this demand for electrical energy, a photovoltaic system can be installed, ensuring a sustainable supply of electrical energy.

4.3 Analysis of the company's 3D plant

See Fig. 9 shows the plant configuration in 3D, highlighting each construction stage of the manufacturing area.

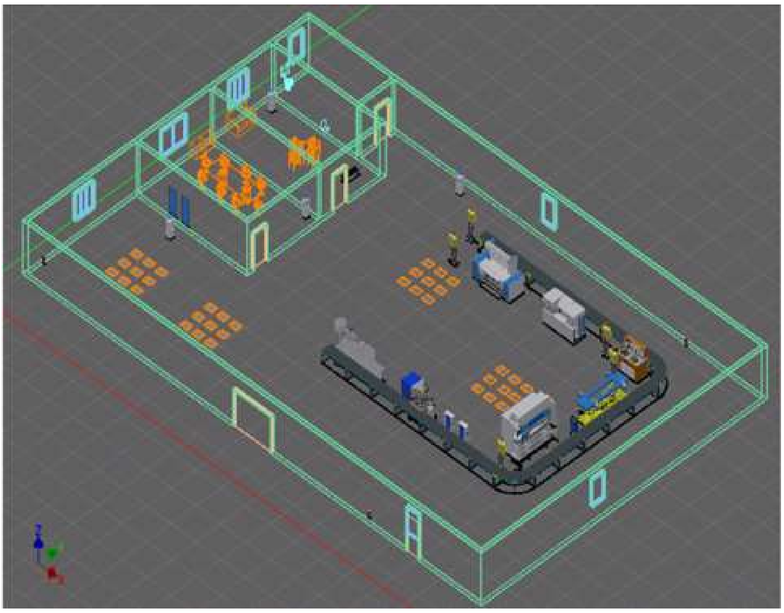


Fig. 9. 3D plant of the photovoltaic module company

Concluding the analysis of results and discussions, the company's final simulation is presented in the form of a 3D plan, in which we can observe each orientation and spaces within the production and movement arrangement. Furthermore, the positioning of employees and the distribution of pallets of finished products and raw materials can be seen.

5 Conclusion

During this project, concepts, information and methodologies were presented to assist in the preparation and sizing of the project aimed at the production of photovoltaic modules, serving as a study base for those who wish to take advantage of this new and promising technology.

To this end, bibliographical research was used throughout this work, the principle of which was the theoretical basis; the descriptive research in which the focus was on gathering information for sizing and also the quantitative and qualitative research, which contributed to the construction of the project.

Firstly, we focus on the theoretical foundation in which we explain and highlight all the principles of the photovoltaic module. A comparison of the types of silicon cells used to produce photovoltaic modules was carried out, as well as a general analysis of the benefits generated when using photovoltaic modules.

Applying the proposed methodology, positive results were obtained regarding the production of photovoltaic modules, as previously seen, the production line has the capacity to produce 720 units. Electricity costs were high, so we applied a proposed solution of installing photovoltaic systems throughout the manufacturing area, ensuring energy supply for the company and promoting sustainable development.
For future studies, it would be interesting to continue the project, carrying out a parallel study to this one, considering an economic survey and possible feasibility of installing this photovoltaic module manufacturing plant.

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