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Virtual Reality Applied in a Thermoelectric Power Plant Planning

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HIGHLIGHTS

- Allows simulation of two types of natural gas supply by the road or the pipeline modals.

- Allows simulating all the necessary structures for the supply of plants through LNG trucks.

- Allows studies about the National Gas Pipeline Network and their accesses.

- Allows locations, establishing connections and simulations in 3-D.

Abstract: The planning of a new thermal power plant is linked to the various decision elements and evaluation criteria. Factors such as the plant's geographic positioning, primary energy supply points, paths, and means of delivery of this primary energy should be analyzed. Similar studies are imposed when studying the change of a thermoelectric plant's primary energy source occurs. In Brazil, several plants are currently investigating the exchange of their primary fuel from oil to gas due to the decrees issued by ANEEL. This paper presents software, which uses virtual reality to assist in the various stages of the planning process and in the analyses that must be performed. This software was developed for the Hidrotermica Group and had as the primary target the Borborema Thermoelectric Power Plant.

Keywords: visualization; virtual reality; planning; gas suppliers; simulation; liquefied natural gas; electric energy production; thermoelectric power plant.

INTRODUCTION

The construction and operation of a power plant is a complex task. Its planning presents challenges, including analyzing several aspects, from technical data of the enterprise's equipment, geographical position, proximity to suppliers, environmental elements, and economic feasibility analysis.

In this project, a computation program was developed to simulate Natural Gas supply logistics to thermal power plants. This process involves constructing port infrastructure sums for Liquefied Natural Gas' receipt, transportation, trucks or the national pipeline network, and its consumption in the plants. The technology used was Virtual Reality [1], which allows the user's total immersion in a virtual environment, capable of manipulating many variables and different situations.

The program allows the simulation of two logistics scenarios for Natural Gas supply: the Road modal and the Pipeline modal.

The program simulates and adds all the necessary structures for plants' supply through trucks (LNG - liquefied natural gas - by truck) in the road modal. It starts with a port station for receiving LNG in LNG carrier, type FSU (Floating Storage Units). The gas is then taken to a truck loading terminal through a Cryogenic Gas Pipeline. This pipeline must be thermally insulated to keep the gas in the liquid state. At the cargo terminal, trucks are loaded with LNG and dispatched to the plants. The range of action of this solution is up to 1,000km from the terminal. The terminal sizing must be done to supply the number of trucks needed to supply all the plants served by the terminal. Upon arriving at the plant, LNG is watered in a unit of its own for this purpose, to be built in the plant. Again, this unit's sizing must meet the gas demand required to operate at the plant's total load.

Using the National Gas Pipeline Network [2,3], Natural Gas arrives at the port on board an FSRU (Floating Storage Regasification Unit) vessel in the Pipeline modal. This vessel, in addition to the transport and storage capacity, also has an integrated regasification unit. Thus, LNG is again converted to the gaseous state still on the vessel and sent to an Integrator Pipeline, connecting the port to the nearest PE (Delivery Point). The EP is the gas injection point in the country's Transportation Pipeline Network. Once injected, the gas can be removed at any of the other Delivery Points of the network, paying for this the usage fee. The choice of a natural gas thermal power plant's construction site is directly related to its distance from a nearby Delivery Point. A Distribution Pipeline makes the connection between the plant and the Delivery Point. A few cities in the country already have some distribution structure. In these cases, the EP is called the city gate.

In both modals, the program assists in decision-making and comparing investment options and assists in the equipment's specification. The main tasks that the program can simulate are:

(a) Determine the best location for the implementation of the plant and port terminals, through the use of georeferenced maps, with thematic layers representing the updated database of national energy infrastructure;
(b) Determine the natural gas demand needed to meet the plants;
(c) Size the size of the vessels, as well as their reloading frequency;
(d) Determine the nearest Delivery Points for both injection and gas removal from the Transport Network;
(e) Estimate the lengths of Cryogenic, Integration and Distribution Pipelines, which are necessary for the simulation;
(f) Size the size of the truck fleet needed to meet the plants;
(g) Size the size of the truck cargo terminal, to be built in the port;
(h) Size the capacity of the watering trees to be built in the plants;
(i) Estimate freight expenses by calculating georeferenced distances;
(j) Estimate the expenses with the tariff of use of the Gas Pipeline Network;
(k) Compare the economic feasibility for construction (CAPEX) or contracting (OPEX) of the infrastructure needed to convert the plants;
(l) Estimate the total cost of logistics in both scenarios.

This paper is organized as follows. Section 2 provides an overview of Virtual Reality and describes the hardware used. Section 3 presents the software "Simulation Environment for Thermoelectric Planning," serving as a manual for its use. Section 4 describes the methodology developed and the calculation memorial implemented in the software. Finally, section 5 describes the methods developed and the calculation memorial implemented in the software and shows two illustrative examples, one in the road modal and the other in the pipeline.

Virtual reality simulations

Virtual Reality (VR) is an advanced user interface that allows you to run computational applications, providing visualization, movement, and user interaction, in real-time, in three-dimensional computer-generated environments [4]. The sense of vision is often predominant in virtual reality applications, but other purposes, such as hearing and touch, can also enrich the user experience [5].

User interaction with the virtual environment is one of the essential aspects of the interface. It is related to the computer's ability to detect and react to user actions, promoting application changes. The user, interacting with a realistic three-dimensional virtual environment in real-time, seeing the scenes be changed as a response to their commands and movements, as occurs in current video games, makes the interaction richer and more natural, generating more engagement efficiency.

In virtual environments, the most direct interaction is navigation, resulting from the user's movement in three-dimensional space through some tracking device, resulting in the visualization of new views of the scenario. In this case, there are no changes in the virtual environment, but only an exploratory tour. Interactions, with changes in the virtual environment, occur when the user enters the applications' virtual space and visualizes, explores, manipulates, and triggers or changes virtual objects using their senses, including the three-dimensional translation and rotation movements the human body.

The virtual reality-based interface allows intuitive user skills and knowledge to be used for handling virtual objects. This type of interaction is performed through unconventional devices, such as viewing helmets or gloves, or the body itself, with gestures and voice commands. The user has the impression of acting within the virtual environment, pointing, grabbing, manipulating, and performing other actions on virtual objects in real-time.

Usually, the permissible delays for the human being to have the sensation of interaction in real-time are around 100 ms, both for vision and reactions of touch, strength, and hearing. This fact imposes a system commitment (processors, software, devices, virtual environment complexity, interaction type, etc.) to operate at minimum rates of 10 frames per second, something around 20 frames per second to better supports animated scenes. Thus, the virtual world's complexity, the devices used, the software, and the system configuration must be adjusted to work with the minimum rendering and reaction rates.

One of the definitions of Virtual Reality that synthesizes the various aspects mentioned above is the following: Virtual Reality is an advanced interface for computational applications, which allows the user to navigate and interact, in a real-time computer-generated three-dimensional environment, using multisensory devices. Virtual reality uses multiple media to emphasize user interaction in the three-dimensional environment by generating real-time images. For this to occur, the computing platform must be suitable for virtual reality applications, presenting good graphics processing capability for rendering three-dimensional models in real-time and supporting unconventional interaction devices to meet multisensory demand.

In virtual reality, the user is transported to the application domain (virtual environment), which can cause him discomfort in the face of the unknown and the need for adaptation and training. The interaction consists of the user's ability to act in virtual environments, promoting changes and reactions to their actions. This fact is the main feature of computer games, being the determining factor for user involvement and application success. For an interaction to take effect, you need a user positioning control (trace) and other system attributes such as: pointing and selecting objects, activating actions, etc.

The Oculus Quest© [6] is a new standalone headset, meaning you don't need any other devices to work. A little different from the Oculus Go© [7], another device also independent but more aimed at incoming users, the quest is geared towards more robust applications. The idea is that the user has an experience closer to what the Oculus Rift© [8] offers than Go's mobility and independence.

The device has four external cameras to identify where the user is and create a safe environment for the virtual sections. Besides, such cameras are also used to determine where the joysticks are in the user's hand. All this without a wire.

The screen has a resolution of 1,600 x 1,400 for each eye, plus space to adjust the screen's distance from the eyeball. The device itself also comes with a set of integrated headphones, compatible with 3D sound.

Although it is independent, it is compatible with computers via USB-C input, which charges the device. It is Qualcomm Snapdragon 835 processor [9] that ensures an excellent virtual experience. Its tracking system has four cameras on the front of the headset. The idea is that it can deliver to the user within the virtual universe a good sense of the real scenario that is around it.

As a differential, it is possible to already save the setup of some rooms or rooms in the device's memory to be installed faster without needing too much configuration. According to the manufacturer, it can identify an area of up to 370 square meters.

Another novelty here is the controls. They are very similar to Touch, the version for Oculus Rift. The main change is that the infrared ring now starts to be turned up and not down, as in the past. According to the company, this makes it easier to identify by the headset.

Simulation environment for thermoelectric planning

Starting the Simulation Environment

For Thermoelectric Planning, the Simulation Environment software is not available in application stores for reasons of confidentiality. Thus, to access it, the user must search the list of programs from "Unknown Sources" (Figure 1 - section A). Applying this filter will be listed as "Borborema VR" (Figure 1 - section B). To run and enter the virtual environment, simply point and click the trigger on the program name. After a few seconds, the company logo appears while the environment is initialized and configured.
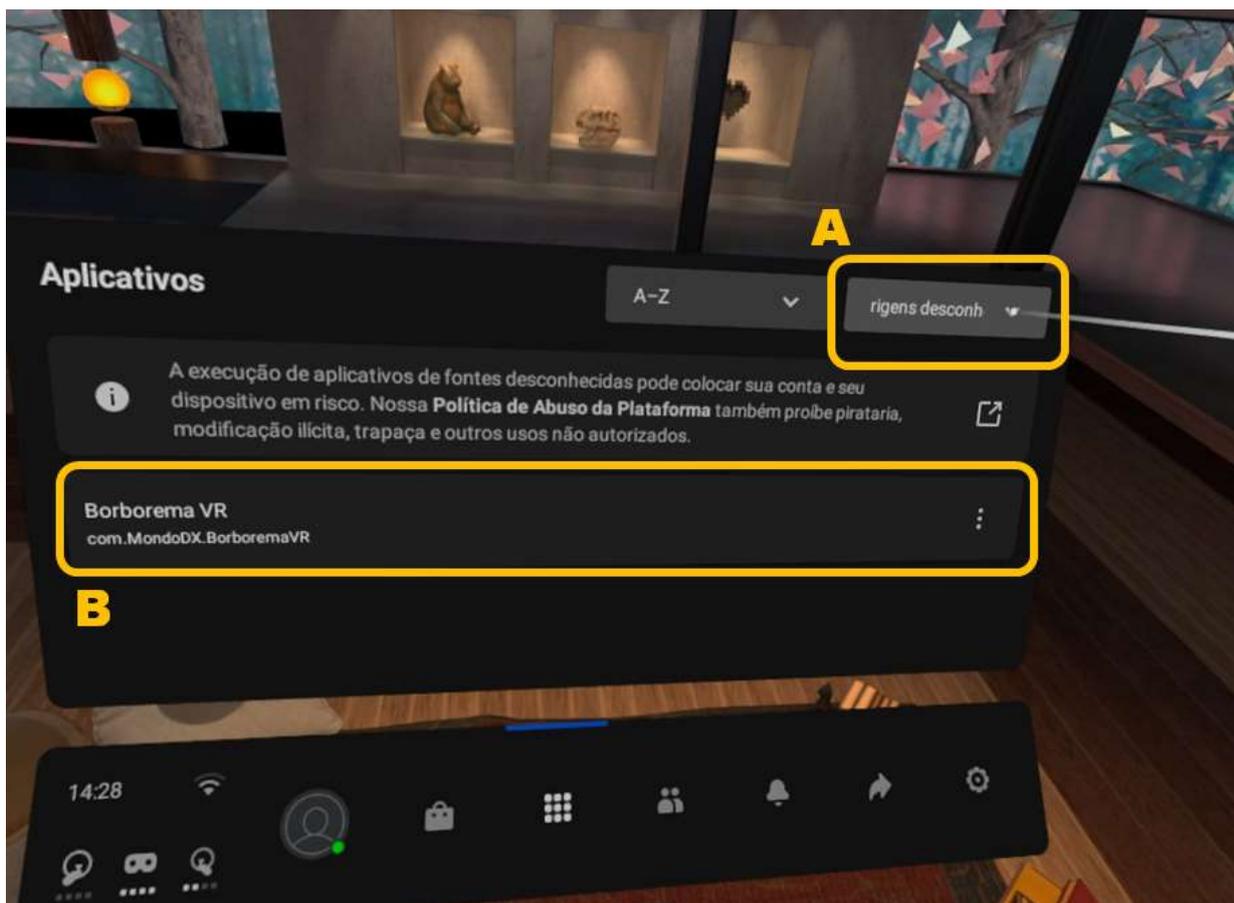
Figure 1. Starting the Simulation Environment.

The virtual desktop has been developed to make work efficient and enjoyable. A workroom has been designed in classic style, with sober colors, not to cause distractions. The living room is decorated with traditional and antique objects, with large windows overlooking nature and good lighting. In Figure 2, a technical drawing board's metaphor was used for the Workspace, with two side floating panels and a central panel. At the bottom of the table, there is a bar of manipulated objects. An iterative map is noted on the table for positioning and representation of simulated scenarios. The user uses the virtual keyboard to enter values in the panes' properties and save or rename sections. Just point to the desired key and press the trigger button.

(a)   (b)   (c)
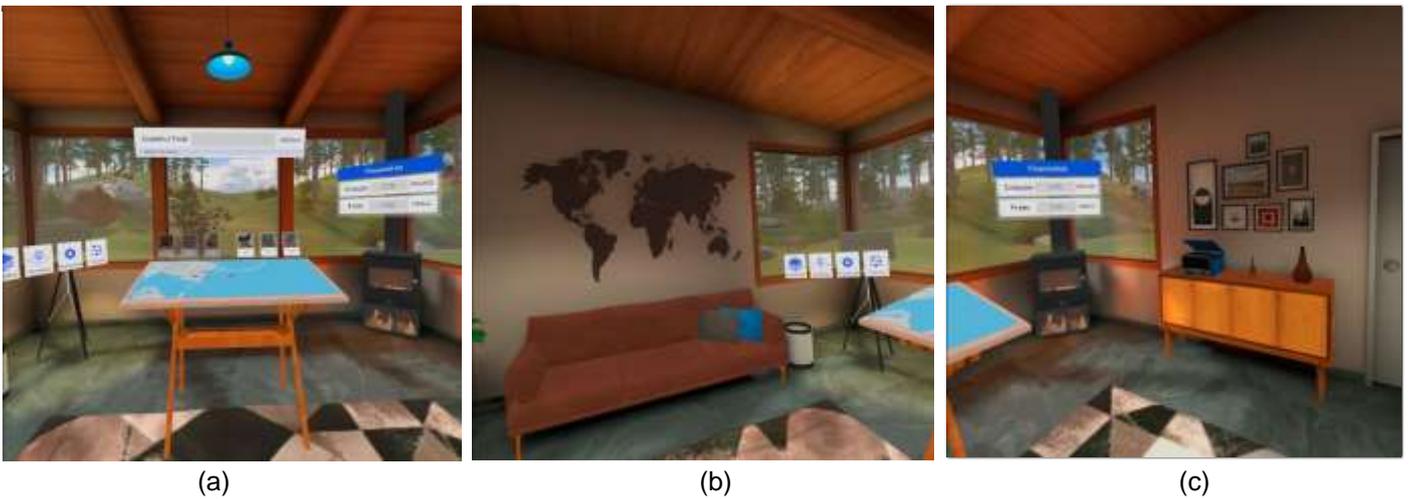
Figure 2. The Workspace: (a) Virtual Desktop, (b) Left and (c) Right Side View of the Virtual Environment.

Command Bar and Layers Panel

The left-hand panel offers several program configuration and control options. There are four buttons: Layers, Sections, Premises, and Presets, as shown in Figure 3. The map displayed on the project table is georeferenced. It has three different display modes: Satellite mode, Map, and Gray Background, as shown in Figure 4. Each of these views is indicated for a specific operation. Map mode is beneficial for the user to locate cities, streets, and neighborhoods on the map. When the desired location is rural, Satellite mode allows you to find a precise location, even if there is no official address. Finally, gray background mode is indicated to analyze operations not connected to the map, reducing background visual pollution.

Figure 3. Command Bar.

(a)   (b)   (c)
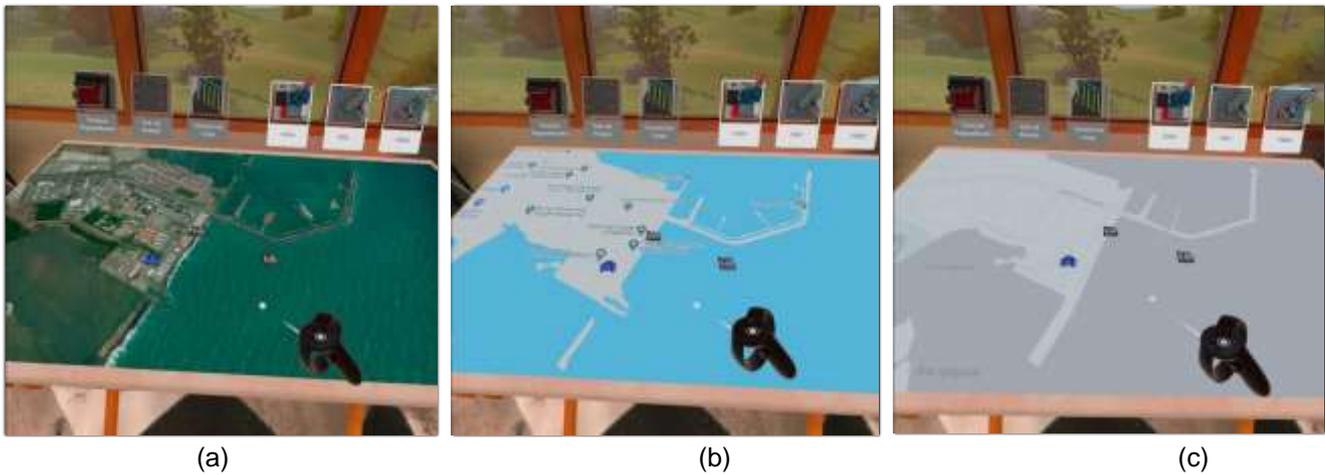
Figure 4. Three map view modes: (a) Satellite mode, (b) Map, and (c) Gray Background.

In Figure 5, the map view radio buttons are the buttons to display/hide the theme layers on the map. The environment has the updated database of all national infrastructure, available on EPE - Energy Research Company. You can choose to display or hide: Power Plants, Ports, Delivery Points, Substations, and Transportation Pipeline Network.

On the map, both existing equipment and those under construction are represented. This fact allows the user to choose and analyze a project's deployment locations according to its proximity to other existing energy infrastructure equipment.

Section Panel, Project Assumptions Panel, and Object Presets Panel

The program allows you to save a simulation section for future reference. This fact is like the disk storage of a computer file. The user must give a name to the section to keep it. Later, the section can be loaded, and the simulation resumed. In this panel, the user can start a new blank section or even delete a saved section that is no longer useful.

Figure 5. Layer Panel.

The Project Assumptions panel stores several parameters that are used in program calculations. These parameters are editable, represent project constants, which, once configured, will hardly be modified. The parameters range from the characteristic of natural gas (its higher calorific value PCS and lower PCI), the compression rate of liquefied gas, to the parameters for loans and financing, such as interest rate and amortization period.

Manipulated objects have a set of pre-established characteristics. These characteristics are assigned to the object at the time of its creation. However, they can be edited and modified through the Presets panel. When changing preset values, the user can use the new values only on new objects, on all objects, or only on objects that have not been reconfigured. The presets available are: the degree of efficiency of the plant, the annual operating time of the plant, the capacity of the transport trucks, and finally, the prices per kilometer for the construction of cryogenic and integrative pipelines. Figure 6 shows the panels described above.

| (a) | (b) | (c) |
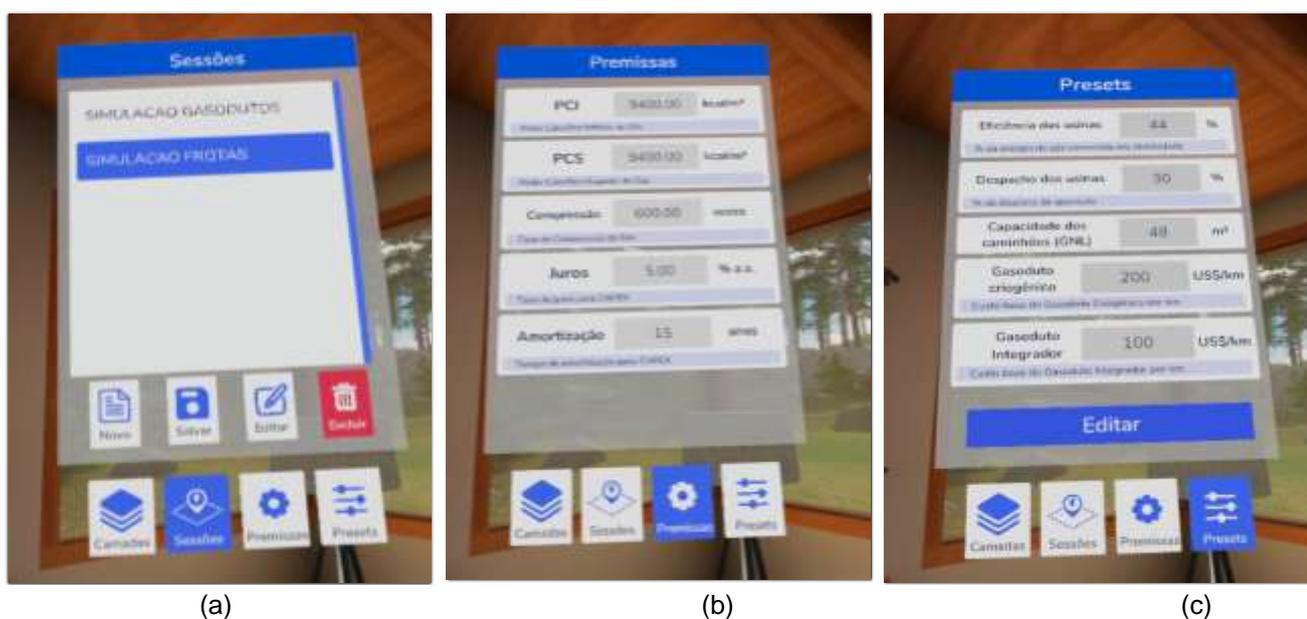
Figure 6. Examples of Panels: (a) Section Panel, (b) Project Assumptions Panel, and (c) Object Presets Panel.

Financial Panel and Central Panel

The two main parameters for calculating logistics costs for supplying natural gas to the plants are the dollar price and the freight value per kilometer. These parameters are indicated in the right panel.

The primary value calculated by the program is the total logistics cost for the simulated situation. This amount is presented in the central panel, in dollars per year. In this panel, it is also indicated whether the current section is already saved or not. Figure 7 shows examples of the Financial Panel and Central Panel.

| (a) | (b) |

Figure 7. Examples of Panels: (a) Financial Panel, and (b) Central Panel.

Manipulated Objects

To perform the simulation, the user must position a set of objects to represent the problem situation being simulated. It can place the plants, FSU and FSRU vessels, truck terminals, delivery points, or substations. Figure 8 shows examples of the manipulated objects.

Figure 8. Manipulated Objects.

When an object is located on the map, the zoom level must be adequate. Thus, the user cannot create objects until the plan is zooming enough to determine the position precisely. The act of grabbing a distant object is done by pointing at it and pressing the gauntlet button. This fact attracts the object to your hand and allows you to hold it while the button on the handle remains pressed. To drop the object to a specific position, the user must point to the desired position and release the button on the hold. Figure 9 shows examples of positioning a thermal power plant on the map.

Thermal Power Plant

After positioning a plant on the map, the user can modify its properties and rename or even delete it. This fact is all done in the plant's property panel, as shown in Figure 10. Fields in darker color are fields calculated by the program. For example, the number of recharges required per day for the plant's operation is indicated. These output values are useful in sizing buildings. Several other values are represented, mainly annual operating values (OPEX) for equipment contracted or built.

Figure 9. Positioning a plant on the map.
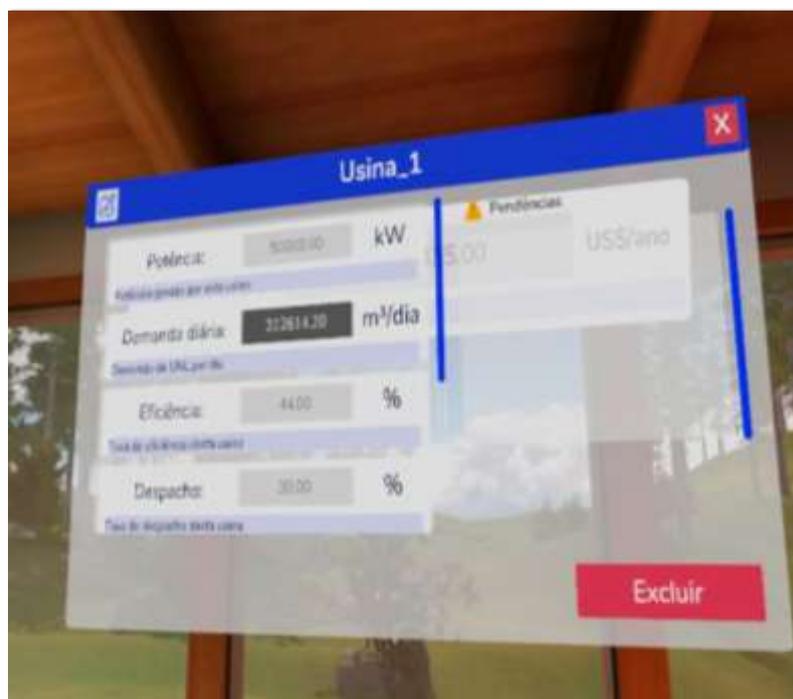
Figure 10. Plant Properties Panel.

FSRU, FSU, and Truck Terminal

An FSRU (Floating Storage Regasification Unit) unit must be positioned in an existing port for a gas supply scenario with pipeline logistics. In this situation, the LNG carrier brings the liquefied gas but delivers it in gaseous injection into the Transport Mesh.

An FSU (Floating Storage Unit) unit must be placed in an existing port to supply natural gas in the liquid state, be loaded in refrigerated tank trucks, and be taken to the plants to be watered and consumed.

In road logistics, LNG is delivered to the plants by a fleet of cryogenic tank trucks, which keeps the fuel refrigerated. When delivered to the plants, LNG passes through a regasification station. The truck terminal should allow the entire fleet's daily loading necessary for the supply in a whole load of the client plants. The yard should enable the trucks to enter and exit quickly to make the loading process as fast as possible. In its dimensioning, it should be taken into account that while some trucks are being loaded, there are others in transit making the deliveries. Thus, not necessarily. All trucks will be loaded simultaneously. In the terminal panel, the user informs the trucks' volumetric capacity to determine the number of refills required for each plant. Figure 11 shows examples of these panels.

(a)

(b)

(c)

Figure 11. Examples of Panels: (a) FSRU Property Panel, (b) FSU Property Panel, and (c) Truck Terminal Property Panel.

Delivery Point and Regasification Unit

A Delivery Point (PE) is a gas entry or outlet point from the transport pipeline network. In pipeline logistics, the injection point is the closest PE to the port since the LNG carrier itself, FSRU is already gassing LNG. Depending on the port infrastructure location, it is necessary to build an integrative pipeline connecting the port to the Delivery Point.

The point of withdrawal of the gas will be the PE closest to the plant. In cities where there is already a natural gas infrastructure, this delivery point is called City Gate. The distribution pipelines make the interconnection of the City Gate to the plant.

At the Point of Delivery, the gas is withdrawn by paying two tariffs: the tariff for using the transport network and the distribution fee. The first is calculated proportionally to the distance between the injection point and gas withdrawal. In this route, the rates of the segments of the mesh used will be charged.

The distribution tariff represents the cost of using the distribution pipelines, which connect the City Gate to the plant. This rate has two installments: the reservation (PRC) and the use (PUC). The PRC - capacity reserve portion - is a fixed amount, contracted by the maximum amount of gas to be supplied per month,

which remunerates the availability of this amount of gas. PUC – the portion of capacity use – is a value proportional to the adequate consumption of gas. These two values are analogous to electrical contracting, where there is a value related to demand and another the energy consumed.

Suppose it is necessary to build a regasification unit in the plants for LNG's receipt and processing. In that case, the program allows analyzing two scenarios: one where the cost of construction of this unit is made by the power plant itself, through an investment (CAPEX). In this analysis, the program uses the assumptions of amortization time and interest rate to calculate the unit's annual cost. Another possibility is contracting such a unit directly from a supplier, who will charge a yearly amount (OPEX) to perform the service. The program allows you to compare these scenarios and check which one is most advantageous.

Figure 12 shows examples of the Delivery Point Panel and Regasification Unit Panel.

(a)   (b)

Figure 12. Delivery Point Properties Panel and (b) Regasification Unit Properties Panel.

PROPOSED METHODOLOGY

This section presents the methodology calculation memorial that was implemented in the simulator. Object-Oriented Modeling (MOO) was used to group the variables and their naming.

The calculation variables were grouped into objects using object Notation.Property for naming variables. They were also divided into main input variables (user-informed), secondary input variables (premises and presets predefined by the program but subject to user change), and output variables (calculated using a formula). Besides, all variables have associated a unit of magnitudes, such as Joule, Km, and MW.

The first chart shows a set of conversion factors and assumptions. Conversion factors differ from assumptions because they are not editable by the user, as shown in Figure 13. The interfaces were written in Portuguese, the Brazilian native language.

Figure 13. General Project Assumptions.

Characteristics of Natural Gas

The Natural Gas object modeling shows the path of energy, from its chemical form, present in the gas, through its VALUES of PCI and PCS (lower and superior calorific value), through the efficiency of burning and the process of generating electricity (Figure 14). It is essential to highlight that Liquefied Natural Gas's great attractiveness is its compression rate (600 times), which means that 1m³ of LNG will contain the energy equivalent to 600m³ of the natural gas gaseous state.
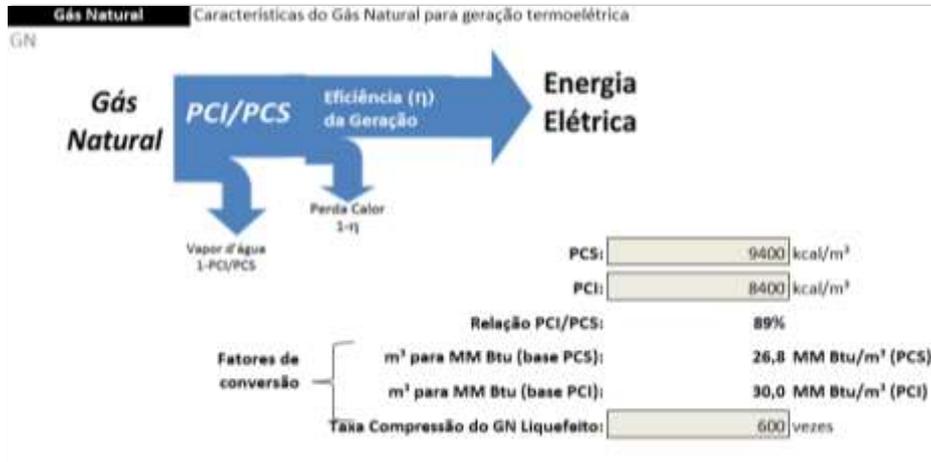
Figure 14. Characteristics of Natural Gas.

Plant Characteristics

The plant object is characterized by its power, efficiency, and percentage of days of the year of operation (dispatch), as shown in Figure15. These data allow calculating the gas demand required for its daily operation, full load, and the annual demand for gas for operation.
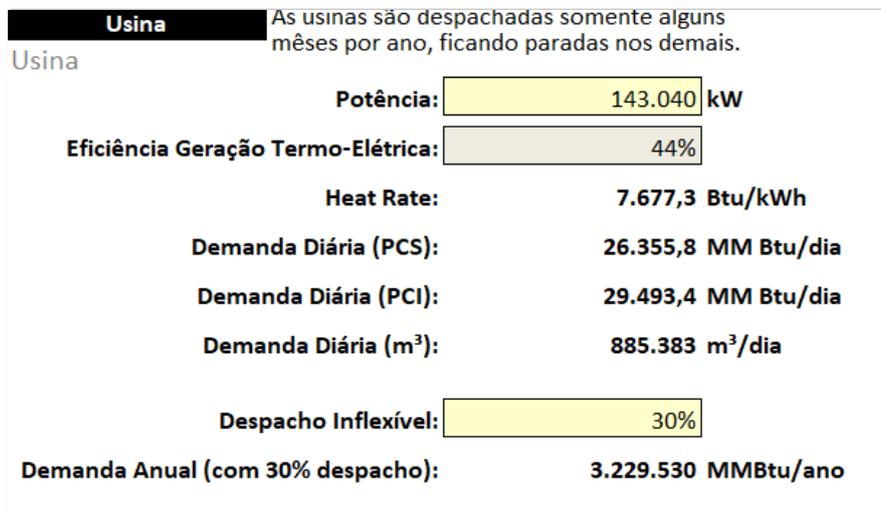
Figure 15. Plant Characteristics.

Liquefied Natural Gas Freight and Integrator Gas Pipeline

In the case of road logistics, the trucks' freight needed to supply the plant is an essential part of the simulation. Here, the main parameter is the distance from the plant to the truck terminal, along with the cost of freight and the trucks' capacity. This window allows you to calculate the amount of gross energy transported by each truck and the number of trucks needed for the plant's daily operation. With this data, you can reach the total annual operating cost (OPEX) with freight.

For the logistics simulation with pipelines, one should consider the Integrator Pipeline construction investment, which will connect the port to the nearest EP (delivery point). In a simulation, this investment is

made through financing, considering the premise of interest (TMA) and amortization time in years. Monthly payments for this financing are considered as annual operating costs (OPEX) of the integrating pipeline.

The program allows the estimation of the total cost for construction of the pipeline, using as a parameter its length, diameter, and unit base cost. Figure 16 shows examples of the above calculations.

(a)   (b)

Figure 16. Examples of the: (a) Integrator Gas Pipeline, and (b) Integrator Pipeline.

Pipeline Network Tariff and Distribution Mesh Tariff

According to the mesh section used, the transport mesh usage charges are indicated in the respective table between the injection and gas withdrawal points. In possession of this tariff, the program calculates the total cost of operation to use the mesh, according to each plant's daily demand.

The distribution rates are reported in the respective table, with their consumption ranges in m³/month and PUC's respective values (Capacity Usage Portion) and PRC (Capacity Reserve Portion). The PUC has calculated the plant proportionally's gas demand, while the PRC is paid regardless of whether the plant generated it or not that month. The sum of both converted into dollars is the operational cost with a distribution of natural gas. Figure 17 shows examples of the above calculations.

(a)   (b)

Figure 17. Examples of the: (a) Pipeline Network Tariff, and (b) Distribution Mesh Tariff.

Other Operating Costs

Finally, the last necessary variables are the annual operating costs (OPEX) of the FSU (road modal), the FSRU (pipeline modal), the Cryogenic Gas Pipeline, and the Regasification to be built in the plant. With all this data, you can reach the total operational cost with logistics in both simulated scenarios (Figure 18).

Figure 18. Other Operating Costs.

RESULTS

Simulation with Road Logistics

In road logistics simulation, the gas path is done in 4 steps: LNG is delivered and stored in an FSU in the port. From there, it is transported by a Cryogenic Pipeline to the truck terminal. A fleet of refrigerated tank trucks is loaded and dispatched to the plants in the road modal. Upon arriving at the plant, LNG is processed and watered to be consumed by the motor generators. Figure 19 shows the Gas Path in Road Logistics. It illustrates a supply situation known as LNG by Truck, where the user creates and positions a plant on the map, positions an FSU at the port, and connects the two through the cryogenic pipeline and truck terminal.
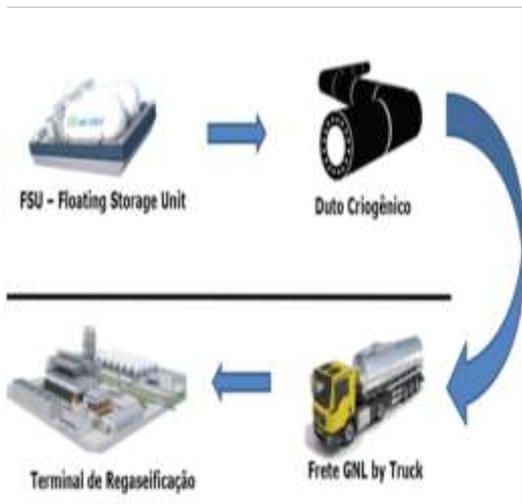
(a)   (b)

Figure 19. Simulation with Road Logistics: (a) Gas Path in Road Logistics, and (b) Example of Road Logistics Simulation.

Simulation with Logistics by Pipelines

In the simulation of logistics by pipelines, the gas path is done in 4 steps: LNG is delivered already watered by the FSRU in the port. The Integrator Pipeline connects the port to the nearest PE for injection into the Transportation Pipeline Network. The gas will travel through several mesh stretches until it is removed in

the PE closest to the plant (City Gate). From this point, it will be taken to the plant through the distribution pipeline. Figure 20 shows the Gas Path in Pipeline Logistics. It illustrates a simulation of pipeline logistics, where the user-created and positioned two plants on the map, positioning an FRSU in the port. Placing the plants connected the plants to the nearest delivery point, creating the distribution pipelines. The same happened at the port, where the program connected the FSRU to the nearest delivery point, creating the integration pipeline.
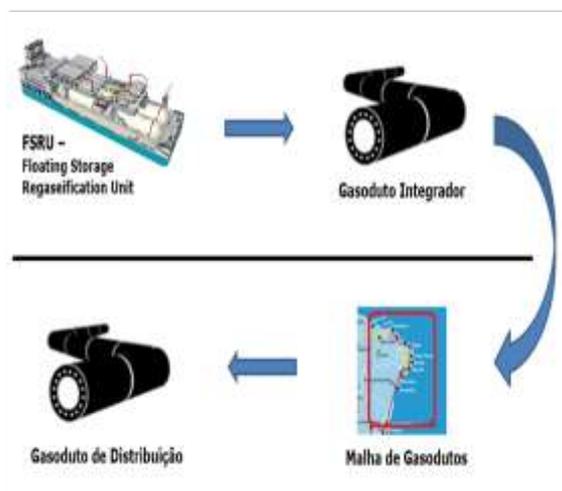
(a)   (b)

Figure 20. Simulation with Logistics by Pipelines: (a) Gas Path in Pipeline Logistics, and (b) Example of Pipeline Logistics Simulation.

CONCLUSION

Virtual reality has the potential to change how several studies are produced today, notably those linked to simulations. Professional can be able to work productively anywhere, simply by using portable devices and immersive monitors. VR has the potential to enable this by creating work environments that do not have the limitations of the physical world, such as restricted space or noisy environments.

This paper presents a computer program based on virtual reality to plan new thermal power plants to their location and primary energy source. Studies on how these primary sources can reach the plant are available and pressed in the computer program. Also, the connection with the power grid can be a reason for the study.

The program is in use at the Borborema thermal power plant, but its use in all Hidrotermica Group plants is under study.

Conflicts of Interest: The authors declare no conflict of interest.

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