The development of a Virtual Lab for distance engineering education due to the COVID-19 pandemic

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RESUMO

Um laboratório virtual para o ensino a distância foi desenvolvido, em caráter emergencial, devido à pandemia de COVID-19, de modo a auxiliar as disciplinas nas quais a aplicação do Desenho Assistido por Computador (CAD) é fundamental. O OpenVPN® foi utilizado para acesso remoto; o VMware® ESXi v6.5.0 foi usado para virtualizar os ambientes; e o Windows Server® 2019 e o DebianTM 10 foram usados como sistemas operacionais. O laboratório virtual suporta 210 usuários simultaneamente 24 horas por dia, sete dias por semana. Os principais resultados indicaram que a plataforma proposta tem um custo 24% menor do que a solução comercial mais acessível do mercado; que a arquitetura do laboratório virtual tem um consumo de energia entre 33 a 50% menor do que as abordagens tradicionais; e que 78,8% dos usuários consideram o serviço oferecido estável ou muito estável, mesmo com mais da metade (57,2%) tendo uma velocidade de internet entre 10 e 30 Mbps.

PALAVRAS-CHAVE: Educação a Distância; COVID – 19; Pandemia; Ensino de CAD; Balanceamento de Carga.

ABSTRACT

A virtual laboratory for distance education was developed during the emergency of the COVID-19 pandemic to support the disciplines in which Computer-Aided Design (CAD) is indispensable. The OpenVPN® was used for remote access; the VMware® ESXi v6.5.0 was used for virtualizing environments; and the Windows Server® 2019 and the DebianTM 10 were used as operating systems. The Virtual Lab supports 210 users simultaneously and is useful 24 hours a day, seven days a week. The main results indicated that the proposed virtual laboratory is 24% less expensive than the most accessible commercial solution on the market; that the architecture of the virtual laboratory has an energy consumption between 33 to 50% lower than traditional approaches; and that 78.8% of the users considered the service offered stable or very stable, even with more than half (57.2%) having an internet speed between 10 and 30 Mbps.

KEY-WORDS: Distance education; COVID-19 Pandemic; CAD teaching. Processing load balancing.

1 INTRODUCTION

The Brazilian Ministry of Education **[1]** authorized the replacement of face-to-face classes for digital media classes to minimize the impacts on education caused by the COVID-19 pandemic on 17th March 2020. In this context, engineering courses at federal universities needed to migrate activities, on an emergency basis, to virtual teaching and learning environments. Although computational tools for distance education are not a novelty, the transition was sudden for most students and lecturers **[2]**. Numerous challenges were suggested immediately, such as the maintenance of accessing a computational infrastructure that allows equal conditions for students to learn at their homes. The purpose of this action is to avoid the withdrawal of students in the face of the new scenario of learning with limited resources. An alternative to overcome the mentioned challenges is the use of virtual labs.

Virtual labs are learning environments where the physical system is virtualized through computer simulations based on software and hardware infrastructure **[3].** El Sayed et al. developed a virtual laboratory to design gears for undergraduate courses in Mechanical Engineering **[4]**. This solution enabled the reduction of physical resources. Valdez et al. **[5]**. implemented a similar idea for teaching circuit theory. Ayas and Altas **[6]**, Peidró et al. **[7]**, and Chacón et al. **[8]** developed laboratories capable of simulating physical control systems. Debacq et al. **[9]** emergently developed a laboratory for virtualizing fundamental experiments to the food engineering master's course during the COVID-19 pandemic. Seidel, Eibl-Schindler, and Dieter Eibl **[10]** developed a virtual lab based on a bioreactor model to allow students to investigate the design and operation of stirred bioreactors independently of time, location, and end device. The user interface used hypertext markup language (HTML) and cascading style sheets (CSS). The web application was generated through Verge3D® 3.9.

El Sayed et al. **[4]** and Valdez et al. **[5]** did not present details about how users perform secure authentication to access the virtualized environment and also did not describe how remote access to the server is performed. In Ayas and Altas **[6]**, the software developed for virtualizing physical control systems was installed only on specific computers, to which users had remote access. Peidró et al. **[7]** and Chacón et al. **[8]** did not present how users accessed the virtual laboratory. In Debacq et al. **[9]**, and in Seidel, Eibl-Schindler and Dieter Eibl **[10]**, information on the cost, time of development, and the number of simultaneous students that can access the platform were not detailed. Therefore, based on the research presented, there is a gap in the theme of remote access authentication to virtual laboratories, given that this is a fundamental requirement for teaching security. Another critical point is the number of simultaneous accesses to virtual laboratories, which can be a restriction for application in subjects involving many students from different undergraduate courses.

According to Jeong et al. **[11]**, there are three leading proprietary solutions for the virtual desktop infrastructure (VDI): a) Citrix® Virtual Desktops Standard; b) Microsoft Windows® Virtual Desktop; and c) VMware® Horizon 7. The three solutions mentioned support essential features for engineering teaching. A common bottleneck with virtual solutions in engineering courses is the graphics acceleration required to perform simulations or computer rendering in real-time. The solutions developed by Microsoft Windows® and VMware® recommend using professional graphics cards. The Citrix® Virtual Desktops Standard solution is cheaper, but the license price can exceed US$ 54,000.00 when considering an application, for example, of 500 users. In addition to the price, the proprietary solutions are usually black-box systems, limiting the flexibility of access according to the application or future customizations.

Aiming to avoid proprietary solutions, Fernández-Cantí et al. **[12]** and Cardoso et al. **[13]** developed customized platforms for remote access to virtual learning environments applied to engineering courses. Fernández-Cantí et al. **[12]** describe the application of the virtual laboratory for the control of a magnetic levitator and an inverted pendulum on a car system. Only teachers can establish which experiments will be available to students in these systems. On the other hand, students needed to install specific software developed by the GilabVir group to access the virtual environment. Cardoso et al. **[13]** and Cabrera et al. **[14]** developed a virtual and remote laboratory to carry out different experiments associated with controlling hydrodynamic systems in engineering education. A web-based platform with client-server architecture was designed. This platform was implemented in JAVA™ and Matlab®. The main challenge of this type of virtual laboratory is the limitation of one user for each available

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physical computer on which the client application is installed.

This study discusses the design and implementation of a virtual laboratory for distance education, applied to Computer-Aided Technical Design (CAD) for Mechanical Engineering and Mechatronics Engineering courses at the Federal University of Rio Grande do Norte (UFRN) in Brazil. The approach developed was innovative since the virtual laboratory architecture performs load balancing inside the available workstations cluster, allowing more than one user per workstation. The virtual laboratory developed also enabled stable and simultaneous remote access for more than 210 students during the COVID-19 pandemic, even under Brazil's slow internet speed conditions. The article also evaluated the students' perception of the proposed solution and conducted a cost analysis.

2 METHODOLOGY

The virtual laboratory was implemented using the computational infrastructure of the School of Science and Technology (SST) and the Department of Mechanical Engineering (DME), both at the Federal University of Rio Grande do Norte (UFRN). It was applied to undergraduate students of Computer-Aided Technical Design (CAD) disciplines for Mechanical Engineering and Mechatronics Engineering. The development of this project was carried out in four main steps: (1) the definition of user and developer requirements; (2) the architecture design for remote access that connects students to virtual machines; (3) the suitability of the solution for engineering education from the students' point of view; and (4) the cost analysis for the development and implementation of the solution. This last point considered software, hardware, and energy consumption costs.

The main user’s requirements for the virtual lab project were:

1a) the platform must be multidisciplinary;

1b) the access to the platform must be intuitive and carried out with credentials managed by the university with minimal software installation;

1c) the platform must be available for connection 24 hours a day and seven days a week;

1d) the virtual experience must be similar to the experience of using a local computer;

1e) the platform must offer a stable service;

1f) the data of the virtual activities must be recorded and quickly retrieved by the users, if necessary.

The main developer’s requirements for the design of the virtual laboratory project were:

2a) The platform must enable the use of engineering software, especially those that require greater graphics card demands and more significant processing needs, based on a Microsoft® Windows operating system, through the remote desktop session.

2b) The platform must integrate different hardware for the end-user.

2c) The time and effort required to install and maintain the virtual laboratory should be reduced when compared with a laboratory based on a personal computer.

2d) The platform must increase the number of users, with adequate processing power for the use of engineering software, compared with the number of physical workstations available.

2e) The platform should allow students to have secured access to resources and services available exclusively on the university's private network.

2f) The platform must allow users to have an equal experience with the services.

2g) The platform must allow users to run all the university-licensed software.

From a hardware point of view, 22 workstations (HP® model Z210), an HP® model Z220 workstation, and 3 Dell® PowerEdge R710 servers were used for the virtual laboratory architecture design. Regarding a software point of view, the following were used: OpenVPN® for remote access; VMware® ESXi v6.5.0 for the virtualization of environments; Windows Server® 2019 and DebianTM 10 as operating systems; FreeNASTM 11 for storing data on a network; and Remote Control Active Directory (RCAD), software developed by UFRN for user management. Considering the mentioned requirements, the proposed virtual laboratory was elaborated with a detailed description to meet requirements and also allow replication at other institutions.

An online questionnaire was developed to verify the adequacy of the proposed solution to students' demands using the Google Forms platform. The questionnaire was applied to two Computer-Assisted Technical Drawing (CAD) disciplines in the second semester of 2020, involving the Mechanical

Engineering and Mechatronics Engineering course. The answers to the questionnaire were not mandatory, and 14 students responded. The main items of interest for evaluation were:
3a) to evaluate the ease of access to the proposed solution;
3b) to understand the stability of the service offered;
3c) to compare the experience of the local with the virtual use of the desktop;
3d) to evaluate the influence of the user's internet speed on the performance of the proposed solution.

From the cost analysis point of view, the proposed solution was compared with three commercial solutions that provide the virtual desktop access service: a) Citrix® Virtual Desktops Standard; b) Microsoft® Windows Virtual Desktop; and c) VMware® Horizon 7. The comparisons used three parameters: a) software cost; b) hardware cost; and c) energy consumption. The software cost analysis of the investment in licensing for each solution considered five user quantities (25, 50, 100, 200, and 500) to provide an overview of the solution. The approach presented in this study assumes the implementation of ready-made solutions when considering the hardware cost composition of the virtual laboratory (FreeNASTM, OpenVZTM, LTSP, and Windows Server® 2019) and the use of an application developed by the SST Information Technology (IT) team, which is designated as RCAD. This software was developed within the scope of the functions of two IT analysts. It is important to note that implementing software configurations for the virtual laboratory required approximately 960 hours of work while developing the RCAD application required 240 hours.

Three laboratory scenarios were considered for the hardware cost analysis. Scenario A is the conventional laboratory, with a workstation per student. On the other hand, Scenario B presents the use of thin clients to provide access through the internal infrastructure of the virtual environment (using HP® t5545 or HP® t5740 thin clients as an output device) for the extrapolation of the solution in future university computer labs. Scenario C considers the virtual laboratory using workstations where the processing is performed, but the access is performed through the user's device (remote teaching). Thus, in the first approach, the principal investment is acquiring computers; and for the second, acquiring thin clients and workstations to enable remote processing. The third approach considers only the investment required to install of the workstations.

The comparison of energy consumption among the proposals considers that the system runs 240 hours per month (e.g., 12 hours a day; 5 days a week; 4 weeks a month). The consumption of the solutions was counted based on the individual computers' consumption. Finally, the prices for these commercial solutions were collected from the Brazilian government's list of prices **[15].**

3 RESULTS AND DISCUSSION

The results of this study are presented in four topics: a) hardware and software solution for the virtual laboratory architecture; b) procedure for secure access to the Virtual Lab; c) suitability analysis of the Virtual Lab; and d) cost analysis of the Virtual Lab implementation and its energy consumption.

3.1 HARDWARE AND SOFTWARE SOLUTION USED ON THE VIRTUAL LAB ARCHITECTURE

Figure 1 shows the information flow besides the hardware and software structure used to implement the virtual laboratory architecture.

The top of Figure 1 shows the network (private and university) - identified with dashed lines - and the equipment necessary to run the Virtual Lab. It is important to note that the network assigned to students (private) is only represented by the number 1. However, this simplifies the system to make it easier to understand since multiple simultaneous connections are possible. Regarding the university network, a couple of subnetworks are applied to the solution: Information Technology Administration (ITA) and the School of Science and Technology (SST). The first is to allow students access to the university's network, and the second is to create credentials and manage tasks in the Virtual Lab. Details of the credentials authentication process to access the Remote Lab will be described in section 3.2

Regarding Information Technology (IT) to support the task of providing the remote session to the students, Figure 1 shows a server with Windows Server® operating system, which contains:

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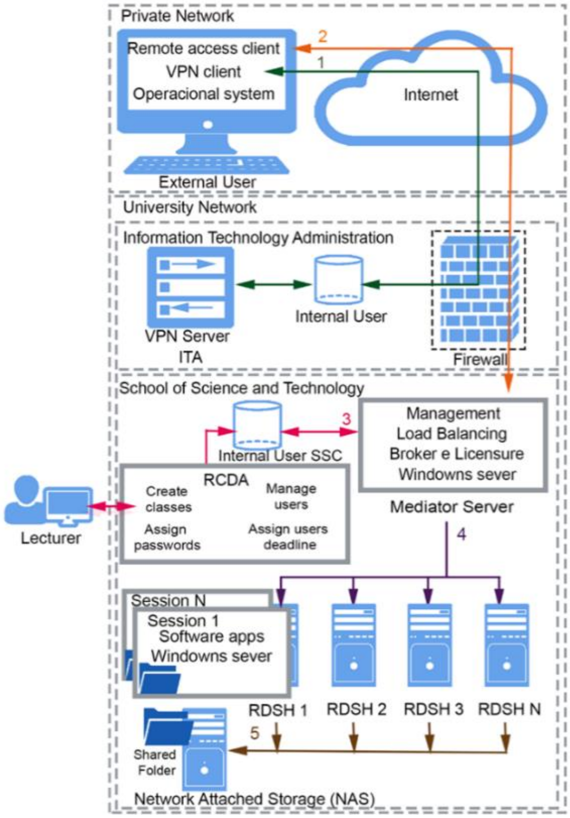
Figure 1- Virtual Lab architecture



Fonte: Authors

a) the management of the collections of services and intermediate services;
b) load-balancing analyzes each Remote Desktop Session Host Server (RDSH) and forwards the request to the workstation with the lowest active load. This tool provides users an equivalent experience since it does not depend on the user's computer settings or updates but on the resources available in the workstations supporting the virtual laboratory. In this sense, the students will have the same resources and processing capacity. This approach meets requirement 2f;
c) the Broker, which is the manager of incoming remote desktop connections to the RDSH;
d) the licensing service that allows users to access the remote service.

The Remote Control Active Directory (RCAD), identified by number 3 in Figure 1, is an application developed by the SST Information Technology (IT) team to enable students to be recognized by the RDSH, a directory services protocol. RCAD manages the credentials previously provided to the students by the lecturers. In this application, lecturers create virtual classes with the number of user accounts; assign initial passwords, and specify the period of use during which the account will be able to log in to the Virtual Lab. The lecturers outside the system carry out the distribution process of these credentials to the students.

The number 4 in Figure 1 represents the direction of the student's request to the RDSH collections. A collection is a group of physical workstations reflecting the existing computational infrastructure of the SST. In each workstation, Windows Server® runs as the base operating system, and the university-licensed software, including those that require greater graphics capacity and greater processing demands according to requirements 2a and 2g. Since the students can access different engineering software, the Virtual Lab can support other disciplines in the engineering programs, such as Programming Languages, Computational Modeling, Linear Algebra, and Industrial Metrology, making this solution multidisciplinary, a requirement considered in 1a.

The desktop virtualization strategy adopted in the architecture is session-based virtualization, which defines the shared use of computational resources allocated on the same physical server intended for multiple users connected in different remote desktop sessions. For Server Virtualization, two strategies were adopted: a) container-based operating system-level virtualization, implemented using OpenVZTM, which requires the Linux operating system to be virtualized to support the container; and b) para-virtualization, implemented using the VMware® ESXi hypervisor, compatible with the Windows® operating system, to support the Administration Service, in this case, Microsoft's Active Directory Domain Services. In both cases, Dell® PowerEdge R710 servers were used. The virtualization of the proposed servers assists scalability, administration, and data management since virtual machines of different configurations are created quickly and can have their state saved at any time, fulfilling requirement 1f. VMM (Virtual Machine Monitor) is the layer between the hardware and the virtual machine. It manages resources, such as CPU, memory, and storage. It is important to note that resources can be easily relocated to other virtual machines, fulfilling requirement 2d. The physical hardware (described in the Methodology) executes the commands, according to requirement 2b.

The system also provides a private area for storing files created by students, which is mapped during the start of sessions and linked to the Network Attached Storage (NAS) service, represented by number 5 in Figure 1. This service runs on a physical part of the RDSH and is linked to the SST LDAP (Lightweight Directory Access Protocol) base. This configuration allows applying restrictions to different users according to their roles. For example, to enable the lecturers to access all the students' folders, with all the reading and writing privileges. On the other side, students have access to their folders, facilitating access to files developed during virtual classes, as defined by requirement 1f.

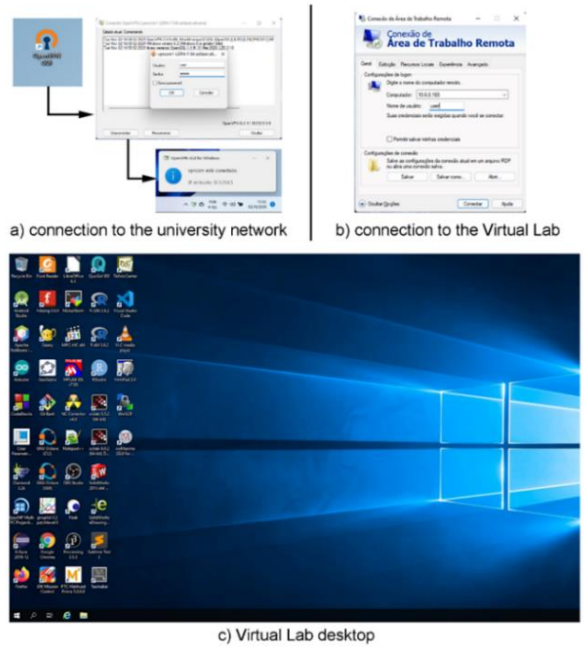
3.2 PROCEDURE FOR SECURE ACCESS TO THE VIRTUAL LAB

From the point of view of information flow, the procedure for secure access to the Virtual Lab is presented in Figure 2.

The first step on a student's personal computer is connecting to the university network. To perform this task, in the student’s operating system (Windows, Linux, Mac, among others), it is necessary to install an OpenVPN® Client. The OpenVPN® is the only software required for student installation. The software connects through the internet with the university VPN Server, as shown in Figure 2a. The student credential provided by the university Information Technology Administration (ITA) will be authenticated and authorized in the database. Hence, the server creates a virtual network through access to the university intranet, according to requirement 1b.

After connecting to the university network, the student takes the second step: connecting to the Virtual Lab. The student uses the Remote Access Connection (native to the operating system or not) and individual credentials, previously registered and provided by each discipline’s lecturers, as can be seen in Figure 2b. This request is processed by RCAD present on the SST network. Then, the student can access to a new computer desktop with all the resources needed for the learning process, as shown in Figure 2c. This procedure makes the virtual lab experience similar to using a local computer, following requirement 1d. The Virtual Lab is also available for connections 24 hours a day and seven days a week, as defined in requirement 1c. All the mentioned procedures are handled by the network security firewall present by the university ITA, respecting the GDPR (General Data Protection Regulation) law.

Figure 2 – Procedure for secure access to the Virtual Lab



Fonte: Authors

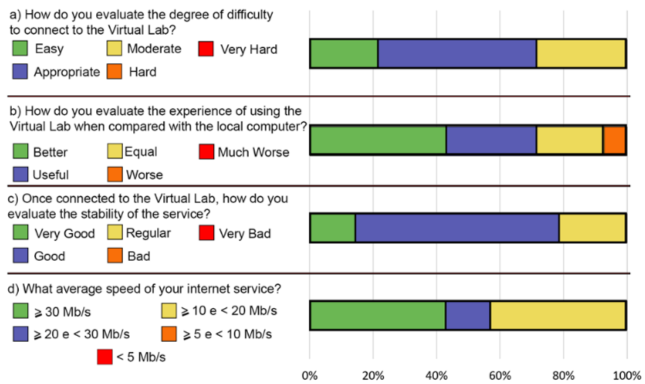
It is essential to describe that OpenVPN® is free and open-source software **[16]**. This software is capable of creating private networks through encrypted tunnels between computers. This easy, safe, and minimal use of software access aims to fulfill requirement 1b.

It is worth mentioning that the architecture of remote access to the Virtual Lab also allows access from university computers connected to the internal network with the same credentials. However, the connection step to the university network is not required. This possibility is essential because it will allow students inside the campus to carry out university Virtual Lab tasks. Later, they can complete the tasks at home and using their personal computer with access to the same Virtual Lab. This proposal eliminates the need to transfer files, problems with software installation, or different versions. However, this alternative will only be tested and implemented in a future non-pandemic context.

3.3 SUITABILITY ANALYSIS OF THE SOLUTION FOR TEACHING ENGINEERING

After the system architecture is finalized, it becomes necessary to understand the solution’s adequacy to the demands of the students. In this sense, four questions were elaborated to assess users' perceptions. Figure 3 presents the questions and the answers of this investigation.

Figure 3 – Questionnaire to validate the adequacy of the proposed solution to users' demands. a) Users' evaluation of the degree of difficulty in accessing the virtual laboratory. b) Users' evaluation of the experience of using the virtual laboratory when compared with a local computer. c) Users' evaluation of the stability of the virtual laboratory. d) Evaluation of users' internet speed.



Fonte: Authors

The first question refers to the degree of difficulty in connecting with the university VPN Server and then to the Virtual Lab. Analyzing the answer "a" in Figure 3, it can be seen that 78.6% of the students evaluated the access to the proposed solution as being easy and adequate, considering the knowledge of an engineering student. It is important to note that no student opined that the access is difficult or very difficult. This perception of users also contributes to fulfilling requirement 1b, which suggests that access to the platform must be intuitive. Question "b" refers to the experience of using the Virtual Lab compared with using a local computer. The result shows that 71.5% of users consider the virtual experience better than the local or assume that the virtual experience is advantageous since it allows access to a computer with better configurations than existing ones at home. Only 7.1% considered it disadvantageous, but this restricted group had personal computers at home with better performance than those provided by the Virtual Lab. None of the students considered the experience with the Virtual Lab worse than the experience with a personal computer, which allows inferring an adequate practical similarity between both scenarios, reaffirming requirement 1d. A similar question was raised by Debacq et al., in which 70% of students stated they were satisfied with learning in a virtualized environment from the point of view of content absorption. In Fernández-Cantí et al. **[12]**, students were asked to evaluate, from 0 (lowest grade) to 10 (highest grade), the experience with the virtual laboratory. In this case, the average grade was 8. Therefore, it is clear that the virtualized teaching approach is a tool, from the students' point of view, suitable for learning laboratory subjects in engineering courses. In addition, the percentage of satisfied students is very similar between the three analyses (between 70 and 80%).

As shown in Figure 3, question "c" refers to the stability of the service during all access to the Virtual Lab throughout the academic semester. At this point, it is essential to describe the levels of stability considered in this study: 1) very stable - without interruptions; 2) stable - up to three interruptions; 3) regular - between four and six interruptions; 4) poor - between seven and ten interruptions; and 5) very poor, more than ten interruptions. The studies presented in the literature and evaluated in this article did not directly investigate the stability, from the student's point of view, of the proposed virtual laboratory applied to engineering education. However, this questionnaire is even more relevant to checking the quality of remote access in a pandemic context. Thus, it is clear that 78.8% of the students considered this Virtual Lab solution stable or very stable, and 21.4% considered the platform regular. This is clear evidence that the proposal is adequate, especially considering that, at peak times, the Virtual Lab was accessed by 210 students simultaneously.

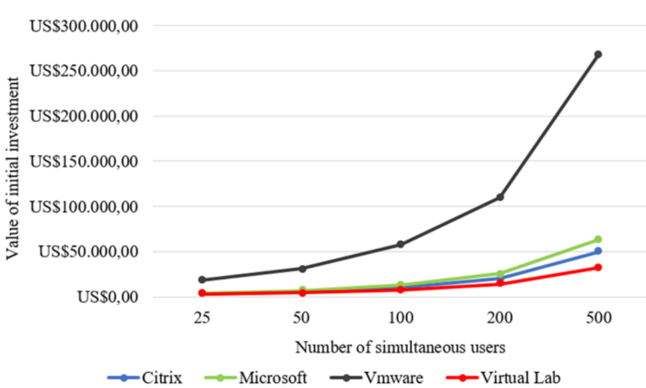
Regarding service stability and the Brazilian reality, analyzing the student's internet speed is essential. In this way, a test using the Speedtest website was required for the students **[17]**. The result is shown in answer "d" in Figure 3. Notably, more than half of the users evaluated (57.2%) had an internet speed between 10 and 30 Mbps. According to the Speed Test Global Index, these values are much lower than the global average of Fixed Broadband, which is 56.09 Mbps **[18]**. Despite this, it can be inferred that, even in conditions of low speeds, the service offered by the Virtual Lab was considered stable or very stable, confirming the fulfillment of requirement 1e. The demand for a service with a high rate of rendered images in CAD, CAE, and CAM software is highlighted here as a critical point for any solution proposal.

According to the results presented for the Virtual Lab proposed, it can be inferred that the solution meets the requirements determined in item 2: such as secure remote access and performed through the student's credentials; and as the load balancing, a more equality teaching tool, since it distributes the computer cluster processing power among all the connections. In addition, from the student's point of view, the proposed solution is suitable for learning Computer-Aided Design subjects in the engineering course. The virtualization of the laboratory experience of this discipline was fundamental in the period of the COVID-19 pandemic. It proved to be suitable for use in disciplines with specific engineering software demands, which require graphics acceleration to perform simulations or render in real-time. Finally, it is essential to highlight that the solution proposed in this study is stable even under conditions of low internet speed.

3.4 THE COST ANALYSIS OF THE PROPOSED VIRTUAL LAB AND ENERGY CONSUMPTION

Once the users' satisfaction with the service offered by the virtual laboratory has been evaluated, it is necessary to estimate the cost to implement the solution when compared with proprietary solutions existing in the market, such as Citrix® Virtual Desktops Standard, Microsoft® Windows Virtual Desktop and VMware® Horizon 7. Figure 4 shows each solution's initial investment concerning the number of simultaneous users.

Figure 4 - The initial investment required by each solution.

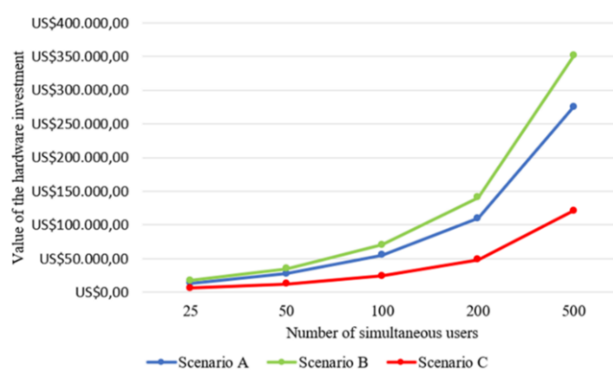


Fonte: Authors

According to Figure 4, it is possible to visualize the investment in software licensing required for five quantitative users contemplated: 25, 50, 100, 200, and 500. It can be noted that the VMware® solution has a higher cost for all evaluated scenarios; in other words, it is the least accessible proprietary solution. For the scenario with 25 users, the cost of the proposed approach is 4, 21, and 85% cheaper compared with the solutions of Citrix®, Microsoft®, and VMware®, respectively. In the case of 200 users, the difference is 33, 48, and 87%, respectively. When analyzing the scenario with 500 users, it is noted that the trend of the higher cost of commercial solutions remains. The proposed Virtual Lab was 36% less expensive than the Citrix® approach, the second most accessible software. The university's demand is between 200 and 500 simultaneous users for the proposed solution. However, it can be inferred that, from the point of view of investment in software, the proposed Virtual Lab suggested in this study stands out positively as more users are served. This result is mainly due to the adoption of session-based virtualization, as explained earlier. It is essential to highlight that the cost of licensing the final applications was not considered in this analysis since, regardless of the approach used, the values for this licensing will remain similar since such software usually adopts the solutions for simultaneous users. Thus, the means of access do not impact the demanded investment.

Three Lab scenarios were adopted: A, B, and C, as explained in the methodology. Figure 5 presents an analysis of the hardware investment for a Lab considering the three scenarios already presented.

Figure 5 - The hardware investment for a laboratory considering the three different scenarios.



Fonte: Authors

Figure 5 compares the three Lab scenarios, again considering the five quantitative of users. The analysis assumes the future use of thin clients at the university Labs. It can be seen that the difference in investment required tends to increase

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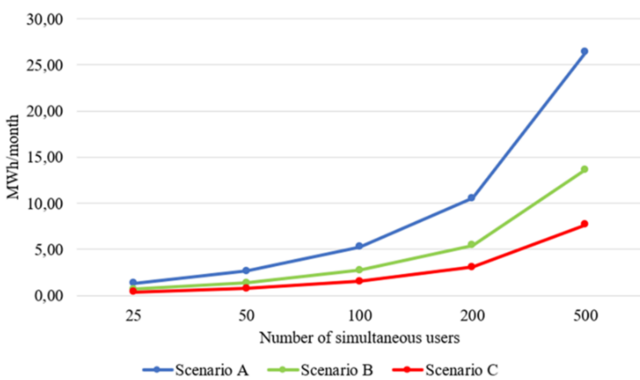
as the number of users also grows. Thus, it can be stated that the cost needed to implement scenario B is not equivalent to the cost demanded by scenario B for environments with a number equal to or greater than 25 workstations. Regarding scenario C, where students use their final devices to access resources, the cost is even lower than the other two scenarios presented. Another feature of the proposed solution is the high availability inherent to the components and architecture of the solution. At same time, the traditional approach has a greater dependence on each station present in the Lab, which negatively impacts downtime (longer maintenance time).

Figure 6 shows a comparison between the energy consumption of each solution. Analyzing Figure 6, it is noted that the proposal suggested in this study, according to scenario C, consumes approximately 56 and 30% of the thin client approach (scenario B) and the traditional approach (scenario A), respectively.

Figure 6 - The energy consumption per month for the three different scenarios.



Fonte: Authors

Therefore, it can be inferred that from the point of view of energy consumption, software, and hardware architecture, the Virtual Lab developed presents significant advantages when compared with commercial proprietary solutions especially when considering the largest number of users. In addition, the Virtual Lab was capable of offering a service, from the user's point of view, stable and secure; one of the main highlights of this study is the feasible performance of the proposed solution under conditions of users' low internet speeds, even in the use of CAD drawing software, which demands high graphic acceleration.

4 CONCLUSIONS

A Virtual Lab was developed due to the demands for distance teaching and learning in the CAD disciplines for Mechanical Engineering and Mechatronics Engineering undergraduate courses imposed by the COVID-19 pandemic. One of the positive points of the proposed solution is to maintain equal conditions among students, as it practically does not depend on the personal computer in each student's home. The Virtual Lab is available 24 hours a day and seven days a week, allowing it to be used in synchronous and asynchronous tasks during teaching and learning processes. Thus, based on the main results presented in this study, the conclusions can be described as:

- Remote access to the Virtual Lab is secure and carried out using the user's student credentials;
- The Virtual Lab presents a similar performance to all users since the load balancing tool was applied to distribute the processing capacity among the students;
- Students described that access to the virtual laboratory platform as easy and adequate (78.6%);
- Students considered the service offered to be stable or very stable (78.8%);
- Students rated the virtual experience better than the local or advantageous experience (71.5%);
- The Virtual Lab architecture demonstrated to be up to 24% cheaper than the approach of Citrix®, the most affordable commercial software;
- The Virtual Lab architecture uses 50 and 33% less energy than traditional approaches.

REFERENCES

[1] BRAZILIAN MINISTRY OF EDUCATION. **Brazilian Federal Register** (2020). Available in: https://www.in.gov.br/en/web/dou/-/portaria-n-343-de-17-de-marco-de-2020-248564376. Accessed in: December, 17, 2021.

[2] CHANDRASEKARAN, Arun Richard. Transitioning undergraduate research from wet lab to the virtual in the wake of a pandemic. **Biochemistry and Molecular**

Biology Education 2020; p. 1–3. DOI: 10.1002/ bmb.21386

[3] ESQUEMBRE, Francisco. Facilitating the Creation of Virtual and Remote Laboratories for Science and Engineering Education. **IFAC PapersOnLine.** v 48(29), p.049–058, 2015. DOI:10.1016/j.ifacol.2015.11.212

[4] EL-SAYED, Azis et al. A multi-user virtual laboratory environment for gear train design. **Computer Applications in Engineering Education**. v.22, p.788–802, 2013. DOI: 10.1002/cae.21573

[5] VALDEZ, Travassos; FERREIRA, Machado; BARBOSA, Maciel. 3D virtual laboratory for teaching circuit theory — A virtual learning environment (VLE). In: **51st International Universities Power Engineering Conference** (UPEC), Coimbra, Portugal, 06-09 September 2016. DOI:10.1109/UPEC.2016.8114126

[6] AYAS, Mustafa; ALTAS, Ismail. A Virtual Laboratory for System Simulation and Control With Undergraduate Curriculum. **Computer Applications in Engineering Education.** v. 24, p.122–130, 2015. DOI: 10.1002/cae.21678

[7] PEIDRÓ, Adrián et al. Virtual Laboratory to Simulate the Control of Parallel Robots. **IFAC PapersOnLine.** v 48 (29), p.19-24, 2015. DOI:10.1016/j.ifacol.2015.11.207

[8] CHACÓN, Jesús et al. Efficient deployment of remote laboratories withTwinCAT-PLCs and EjsS Plugins. **IFAC-PapersOnLine**, v.55, p. 326 – 331, 2022. DOI: 1016/j.ifacol.2022.09.300.

[9] DEBACQ, Marie et al. Delivering remote food engineering labs in COVID-19 time. **Education for Chemical Engineers**. v. 34, p.9-20, 2020. DOI:10.1016/j.ece.2020.10.002

[10] SEIDEL, Stefan; EIBL-SCHINDLER, Regine; EIBL, Dieter. Laboratory-independent exploration of stirred bioreactors and their fluid dynamics. **Education for Chemical Engineers**.v42. p. 80-87.2023. DOI: 10.1016/j.ece.2022.10.001.

[11] JEONG, Doowon et al. Investigation Methodology of a Virtual Desktop Infrastructure for IoT. **Journal of Applied Mathematics**. p. 1-10. 2015. DOI:10.1155/2015/689870

[12] FERNÁNDEZ-CANTÍ, Rosa et al. An Open Source Multiplatform Virtual Laboratory for Engineering Education. **International Journal of Online and Biomedical Engineering** v. 8(3), p. 50 – 55, 2012. DOI:10.3991/ijoe.v8iS3.2267

[13] CARDOSO, Alberto; VIEIRA, Miguel; GIL, Paulo. A Remote and Virtual Lab with Experiments for Secondary Education, Engineering and Lifelong. International **Journal of Online and Biomedical Engineering.** v. 8 (2), p.49 – 54, 2012. DOI:10.3991/ijoe.v8iS2.1984

[14] CABRERA, Margatita et al. GILABVIR: Virtual laboratories and Remote Laboratories in Engineering. A teaching Innovation Group of Interest. In: **IEE EDUCON Education Engineering 2010 Conference.** Madrid, Spain. 14 – 16 April 2010. 1403–1408. DOI:10.1109/educon.2010.5492362

[15] BRAZILIAN MINISTRY OF ECONOMY. Brazilian Government **List of Price.** (2020). Available in:https://paineldeprecos.planejamento.gov.br/. Accessed in:10 April, 2020.

[16] OPENVPN. **Home page**. (2021). Available in: https://openvpn.net/. Accessed in: 17 December, 2021.

[17] SPEEDTEST. **Test of Internet Speed.** (2021). Available in: https://www.speedtest.net/pt. Accessed in:17 December. 2021.

[18] SPEEDTEST **Global Index**. Fixed Broadband: Global Median Speeds. (2021). Available in https://www.speedtest.net/global-index. Accessed in: 17 December, 2021.

DOI: 10.25286/repa.v8i3.2490