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Multi-Sensory Immersion to Improve the User Experience in the Decision-Making Process

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Abstract

This work addresses the need to have a remote immersive multi-sensory virtual environment in which people can come together to make collaborative decisions remotely in real-time, allowing decision-makers to feel as if they were in a Decision-Making Center in person, but with the advantages offered by multi-sensory, immersive, remote, collaborative virtual reality in real-time. Therefore, software architecture is proposed that allows the creation of Multi-sensory Virtual Decision-Making Centers (MVDC) with the capabilities of being collaborative, immersive, and remote in real-time. Together with this architecture, a multi-sensory environment was created, this MVDC has the characteristics and capabilities to carry out remote collaborative decision-making sessions in real-time in addition to adding an immersive multi-sensory experience while using it, ensuring that the sense of presence among decision-makers is not lost and allowing the remote decision-making session to be as similar to a face-to-face session.

Keywords: Decision-making; Decision-Making Center; Multi-sensory virtual environments; Virtual reality; Human-computer interaction; User experience.

1. Introduction

The present work proposes the creation of a multi-sensory immersive system for the remote management of scenarios in the decision-making process. In daily life, the human being is related to the real world in an intrinsically multi-sensory way since we take information from multiple input channels to form a coherent unified perception [1], so the multi-sensory systems were inspired by the vision that an interface that allows multi-sensory inputs and outputs would allow to have intuitive interactions similar to the real world [2].

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with an effectively combining and computationally representing visual and tactile exercises can generate a great immersion in the realization of various tasks, such as training, and it is essential to improve overall usability in simulations [3].

The next relevant topic is user experiences, in which a study conducted by Hassenzahl and Tractinsky [4] this concept is described as a mix between human-computer interaction with beauty, enjoyment, pleasure, and personal growth that satisfies general human needs [5].

Finally, decision-making, in general, is the process when two or more people, called decision-makers, must agree on a solution, although they may prefer different action plans due to different perceptions of information, they must reach a consensus to achieve a shared goal [6]. To carry out the decision-making process, there are Decision-Making Centers, which are technological facilities that involve actors actively to visualize solutions to complex interdisciplinary problems. These problems usually require collaborative efforts, resources, and experience from different organizations. These centers offer the mechanisms to unite the organizations involved in a problem because the collaborative, computer, and visualization technologies can explore the problem, share, analyze, visualize data and evaluate solutions from different perspectives [7].

The work, in general, will address part of these concepts mentioned to support the proposed system, which consists of a multi-sensory system that will support the management of scenarios in the decision-making process, synchronously, remotely, and in real-time will allow the user to have a more immersive relationship in part of the decision-making process.

1.1. Motivation

At present, the creation of multi-sensory environments is growing to cover real needs that can be simulated remotely, in this case, based on decision-making, there are currently Decision-Making Centers that are technological rooms in which Information can be presented on a large scale and decisions can be made within an environment controlled by the participants, but the number of these Centers available is limited and access to these Centers has been complicated since the start of the period of confinement by the current global pandemic, hence the proposal to design a multi-sensory environment in which decision-makers can have immersive remote access and interact in a similar way as in Decision-Making Centers to develop collaborative decision making sessions within of an environment controlled by decision-makers remotely and in real-time, simulating being physically in the Center without requiring physical presence or availability of the facility, but still being able to make use of all its capabilities.

1.2. Hypothesis and Research question

To guide the study, based on the analysis of the state of the art on related topics, we have raised the following hypothesis:

H1: A synchronous relationship at a distance with a multi-sensory, remote, collaborative, real-time, and immersive environment will allow users to have a better manipulation of the data, maintaining a relationship among decision-makers and will provide a new form of interaction supported with devices, facilitating the creation of prospective scenarios and improving the user experience in the process of decision-making.

Along with the hypothesis, the following research question arises:

RQ1: How can the current user experience in the decision-making process be improved, in terms of remote interaction, communication, and presence, by integration of a multi-sensory, remote, collaborative, real-time immersive environment, provided by a software system for scenario management?

1.3. Scope and Limitations

As part of the scope of this work, it is sought to investigate the main use of Decision-Making Centers, as well as their main characteristics and benefits. Also, it seeks to create an immersive and collaborative multi-sensory environment to carry out decision-making sessions remotely in real-time as an alternative to Decision-Making Centers. Finally, we will try to test the collaborative immersive multi-sensory environment to seek to answer the research question and try to validate the hypothesis of this work.

As part of the possible limitations that may arise when developing this work, we can mention the difficulty in finding public information on the functionalities and characteristics of the Decision-Making Centers. In addition, a suitable configuration of software, hardware, and complements of both must be found, to successfully achieve the integration of all the functionalities and characteristics that the multi-sensory environment will have. The last limitation that will be had will be to find a good method to show all the characteristics and functionalities of the multi-sensory environment to seek the validation of these characteristics and benefits in comparison with the Decision-Making Centers.

1.4. Contributions

Collecting information related to Decision-Making Centers, collaborative decision-making, remote interaction, and multi-sensory human-computer interaction, the need to implement a remote Multi-sensory Decision-Making Center was found, in which the process of decision-making and data analysis can be carried out in a collaborative, immersive, remote, and real-time manner, thus allowing the ease of use of the Decision-Making Centers to be increased remotely without losing the sense of presence.

In this work AMVCD is proposed, an architecture to create multi-sensory environments for multi-user decision-making in which collaborative virtual reality is used to carry out the decision-making process remotely in real-time.

In addition, based on this architecture, MVDC is presented, which is a multi-sensory, collaborative, immersive, remote environment in real-time, in which an improvement in the user experience is provided through access to an immersive virtual reality version of a Decision-Making Center in which decision-makers can carry out the collaborative decision-making process remotely in real-time without losing a sense of presence.

2. Methodology

This work was developed under a methodological system where an initial review of the state of the art was carried out for the creation of background and the identification of the area of opportunity, then an in-depth review of the state of the art was carried out for the creation of the theoretical framework and define the contribution, subsequently, a systematic review was carried out on the related work where the area of opportunity was validated and the contribution was refined. After this, based on the unified process methodology, an architecture was created to create virtual reality environments, multi-user, collaborative, immersive, remote, multi-sensory, in real-time, and a multi-sensory environment was developed based on said architecture. Afterward, tests were carried out for the validation of the architecture and the multi-sensory environment, and finally, an analysis of the results is carried out where the hypothesis is validated, the research question is answered and the conclusions and future work emerge.

3. Theorical Framework

3.1. Collaborative Decision-Making

Decision making is commonly defined as the act of choosing an available option among several possibilities that have different benefits and costs [6], considering that this option is chosen through a positive consensus on the part of all decision-makers. Currently, there are many situations in which a group of people must decide when participating in a group of information and discussion [8] so that the definition of collaborative decision-making emerges.

Collaborative decision-making is an interactive process to negotiate action plans and thus achieve a shared goal, therefore, this type of decision-making is a form of collaboration that allows you to create as a decision-maker a mental model of decision status of other decision-makers [6], and this information should be immediately reflected in the views of decision makers [9]. In collaborative decision-making, the exchange of knowledge and communication among all decision-makers is considered the main factor to achieve a satisfactory consensus of decision making [10].

3.2. Decision-Making Center

To carry out the decision-making process, there are centers that seek to help decision makers to visualize solutions for complex problems, these centers provide experience under cutting-edge technologies in collaboration, visualization, modeling, and data simulation. In addition, to provide prototype creation services and improve the experience in the decision-making process. Also, interdisciplinary topics are addressed and applications developed to address challenges in areas such as health, sustainability, education, innovation, safety, among others [11].

Usually, a traditional Decision-Making Center can be seen as a meeting room characterized by specific display technologies and seat availability that allow a group of people to interact with the data and each other to assess a decision-making situation and find a solution. This traditional Decision-Making Center regularly have a configuration like the following: it is a round room with seven curved screens to show models, graphics, and other visual digital content, it also can record and/or transmit audio, and video, as well as tools to collect various data (Figure 1). Along with this, the traditional Decision-Making Center can also be extended to virtual meeting rooms and accommodate remote participants [12].

Figure 1: Decision-Making Center of the Tecnológico de Monterrey, Mexico City Campus [13].

3.3. Multi-sensory environments

When we refer to multi-sensory environments we mean environments in which we need more than one sense to accomplish the tasks. Commonly the main sense is sight, although some of the other senses are necessary to complete most tasks. Sometimes it is necessary to perceive the environment in more detail and we use the senses unconsciously to obtain the information we need [14].

Also, it can be said that multi-sensory feedback can improve accessibility in general and the perception of the virtual environment, collision events become more realistic and users can achieve greater performance when performing tasks with greater precision [14].

Also, Díaz and his colleagues [14] mention that improving the interaction and perception between humans and computers is a continuous challenge, so there has been a need to improve or increase the immersion and interaction of users in virtual reality systems this motivated by the aggregation of the use of additional senses in the process.

4. Related work

This section presents the Decision-Making Centers and their characteristics according to each case, as well as an analysis of the remote access options and the types of remote interaction that the Decision-Making Centers currently have, allowing us to glimpse the possible areas of opportunity for improvement.

4.1. Decision-Making Centers

Currently, there are several Decision-Making Centers that were created to cover the main needs of decision-makers to carry out decision-making sessions in a place where the visualization and analysis of decision-making models are facilitated.

The Arizona State University, Decision Theater (ASU-DT) works together with various experts and combining data analysis, simulation modeling and graphic design to create interactive software applications that allow users to interact with data, build, and compare scenarios within an established system, created under a specially designed, and structured platform for collaboration and informed discussion (Figure 2). Decision-makers meet in the decision-making room (Drum) for presentations, facilitated commitments, and modeling sessions [11].

Figure 2: ASU-DT Room [12].

Another Decision-Making Center is the Huazhong University of Science and Technology – Visdec Electronic Decision Theater (Figure 3), that helps university, government, and business representatives using the facility make better decisions for a variety of programs. The 3D capability of the system is used in urban planning and urban development to aid decision-making in public management. The theater is spacious and offers a wide display area for unique applications, or the option to run multiple applications collaboratively on separate areas of the display canvas to operate collaboratively on screen [15].

Figure 3: Visdec Electronic Decision Theater [15].

There is also the Metropolitan State University of Denver – CAVEA Theater (Figure 4), what is the Center for Advanced Visualization and Experimental Analysis. It was conceived as a community resource to facilitate collaborative and complex decision-making. The space is flexible and adaptable to cater to a variety of types of inquiries, events, and purposes [16]. This DMC is a space with advanced technology, which allows users to make better decisions through the use of computer modeling and simulation and allows users to analyze their decisions and policies before applying them. In this DMC, students and teachers from almost all disciplines can use theater for research, presentations, and simulations [17].

Figure 4: CAVEA Theater [16].

Also, Monash University has the CAVE2 (Figure 5.a) & Future Control Room (Figure 5.b), the Monash CAVE2 installation is a 2D and 3D virtual reality environment that can be programmed to render large and complex data sets with unmatched clarity. Along with this, it allows immersive viewing of very large images from various sources and enables interactive exploration and characterization of mapped or imaged environments. Plus, it enables collaborative and immersive review of design models, building plans, architectural spaces, and more [18].

In addition to this, the Future Control Room was created in a joint location with Monash CAVE2, which offers a unique collaboration space. At the core of an effective control room is the ability to capture and display large numbers of heterogeneous data sets in real-time, along with infrastructure, demographic, and weather data [19].

a) **b)**

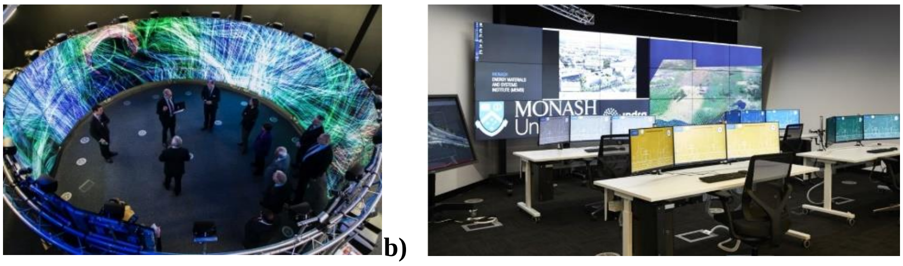

Figure 5: a) CAVE2 [18] and **b)** Future Control Room [19].

The Portland State University Decision Theater (PSU-DT) was designed for university researchers and regional stakeholders (i.e. governments, private companies) to work on projects linking datasets, visualization, and decisions (Figure 6). This is a facility equipped to displaying multiple smaller images or one large image, and facilitating video conferencing, data exchange, and more in a modular collaborative environment [20].

Figure 6: Portland State University Decision Theater [20].

Also, in the Tecnológico de Monterrey, México City campus, there is the Centro para la Toma de Decisiones (TEC-CTD), that presents an adaptable software to different process simulation configurations. The hardware presented by this Center (Figure 7), as well as its architecture allows great flexibility in its implementation, supporting a wide variety of deployment equipment, that allows decision-makers the correct interpretation of the implications of each scenario within a Center for Decision Making [21].

Figure 7: General view of the stationary TEC-CTD [21].

The University of Alaska Fairbanks Decision Theater North (UAF-DTN) is a space that is not used as a DMC but its characteristics are similar to those of a DMC (Figure 8), they have used for dozens of seminars, webinars, training, meetings and thesis defenses. The Theater was proposed as a way to present massive volumes of understandably and interactively data. As its name implies, promoting collaboration and decision-making, both inside and outside the academy, is the ultimate goal of the room [22].

Figure 8: UAF-DTN [23].

Finally, the World Resources Simulation Center [24] is a project of the Global Energy Network Institute, this is a collaborative, and immersive visualization facility where you can see problems and solve them working together [24].

Table 1: Characteristics from the collected DMC information.

DMC	Number and type of Screens	Organization of the screens	Audio and video type	Type of remote access	Type of remote interaction
Arizona State University – Decision Theater	7 screens	260 degrees curved	NA	Video conference	Voice, camera view
Huazhong University of Science and Technology – Visdec Electronic Decision Theater	8 projectors	240 degrees curved	Stereo mode audio, 3D video	Video conference	Voice, camera view
Metropolitan State University of Denver – CAVEA Theater	7 projectors	270 degrees curved	High fidelity audio, 3D video	Video conference	Voice, camera view
Monash University-CAVE2	84-million-pixel stereoscopic screen	Curved cylinder	Surround audio, 3D video	NA	NA
Monash University-Future Control Room	37-megapixel screen	wall	NA	NA	NA
Portland State University – Decision Theater	7 mondopads	3 infocus, 4 in walls	Speaker bar audio, video	Video conference	Voice, camera view
Tecnológico de Monterrey, Mexico City Campus – Centro para la Toma de Decisiones	7 screens	270 degrees curved	Speaker bar audio, video	Video conference	Voice, camera view
University of Alaska Fairbanks – Decision Theater	7 screens	semicircle	Audio, video	Video conference	Voice, camera view
Global Energy Network Institute – World Resources Simulation Center	12 screens	NA	Surround audio, video	Broadcast live	NA

4.2. Analysis

From the collection of information from the Decision-Making Centers characteristics from Related work Section 4.1. and Table 1 derived from that related work, the following analysis can be carried out and the main areas of opportunity can be revealed to improve the experience of decision-makers when participating in remote decision-making processes.

Based on the information collected on the Decision-Making Centers, it can be indicated that these type of

Centers is used mainly as areas intended to facilitate the realization of decision-making sessions by means of the large-scale visualization of the models to be analyzed, in addition, facilitates interaction with decision-making models and scenarios, and allows decision-makers to participate in person in a space intended to carry out the decision-making process in a structured and controlled way in real-time that facilitates study and analysis of the models facilitating reaching a consensus.

Based on the related works trend, it can be noted that certain trends are present with respect to the visualization of data, the availability of audio and video, and the types of remote access, which are presented in Figure 9. It can be noted that most of the Decision-Making Centers have at their disposal use audio and video to present and communicate the decision-making session, in addition, most of these Centers use a visualization display of 7 screens with a curved distribution and mainly use video calls as a form of remote access, along with this it can be seen that no Decision-Making Center has an environment in which immersive multi-sensory interactions take place in which decision-makers full remote access to a decision-making room where decision-making sessions can be held without losing a sense of presence and improve the user experience compared to the use of video conferencing.

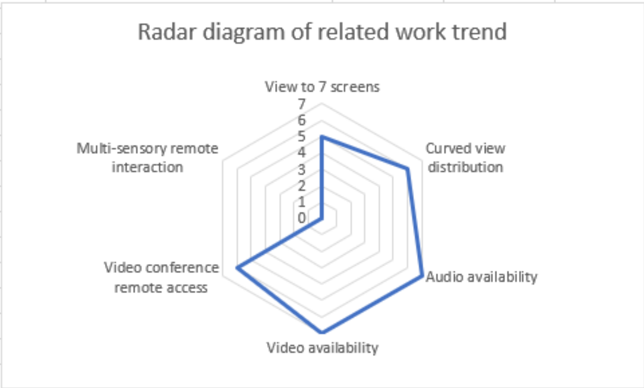

Figure 9: Radar diagram of related work trend.

Based on the trends of related jobs and the current confinement situation due to the global pandemic situation, there is a need to create environments to work remotely in decision-making sessions in a way that does not lose the sense of presence and the current user experience can be improved by participating in remote collaborative decision-making sessions, so the next section presents the proposal for the creation of a multi-sensory virtual reality environment in which decision-makers can participate in the sessions in a unique way completely remote immersive in real-time.

5. Proposed solution

Derived from the state of the art and related works on Decision-Making Centers, it was identified that an area of opportunity in remote access through the creation of a virtual environment where a sense of multisensory and collaborative immersion is presented to carry out decision-making sessions. Next, a proposal will be explained to address the need to improve remote access to Decision-Making Centers by offering an architecture for the creation of multi-sensory virtual environments as an alternative for remote access and the implementation and tests of said architecture.

Currently, the Decision-Making Center presents a multi-screen display mode for the visualization, manipulation and analysis of possible scenarios through forms and graphics, as the case may be [21]. What is desired to improve this user experience, at the remote access level, is to present a methodological proposal for the decision-making process applied in the Decision-Making Centers, in which decision-makers can view, edit and analyze the different decision-making models in a virtual world, in which those involved can work remotely, in real-time, interacting in an immersive multi-sensory way with a Virtual Decision-Making Center.

In addition to being able to manipulate the variables of each decision-making model, through the use of touch control, decision-makers will know, in real-time, that their important variables have been modified, allowing decision-makers to be able to address immediately to the other decision-makers, seeking to clarify the modification of said variable, in order to avoid or control changes in the decision-making model that may affect the careless decision.

For the implementation of the system, we propose two main actors, who can lead to other roles present in the decision-making process. First, we introduce the promoter, who is in charge of presenting the problem to be treated and managing the decision-making process [25]. This actor has the characteristics of a chairman, who is a participant who is allowed to carry out more management actions than other participants [26]. Then we introduce the decision-maker, who can interact and participate in the decision-making session in an immersive multi-sensory collaborative remote real-time way. In addition, the system takes care of communication between decision-makers, updating the model, and real-time feedback for decision-makers during the process.

5.1. AMVCD: an Architecture for a Multi-sensory Virtual Environment for Collaborative Decision-making

Next, we present the description of AMVCD, an architecture proposal, Figure 10, which will be used for the creation of the alternative multi-sensory environment for remote access to Decision-Making Centers in which virtual reality with control devices will be used touch, and a client-server connection for communication between multiple actors in real-time. The following paragraphs will describe each of the elements that make up this architecture.

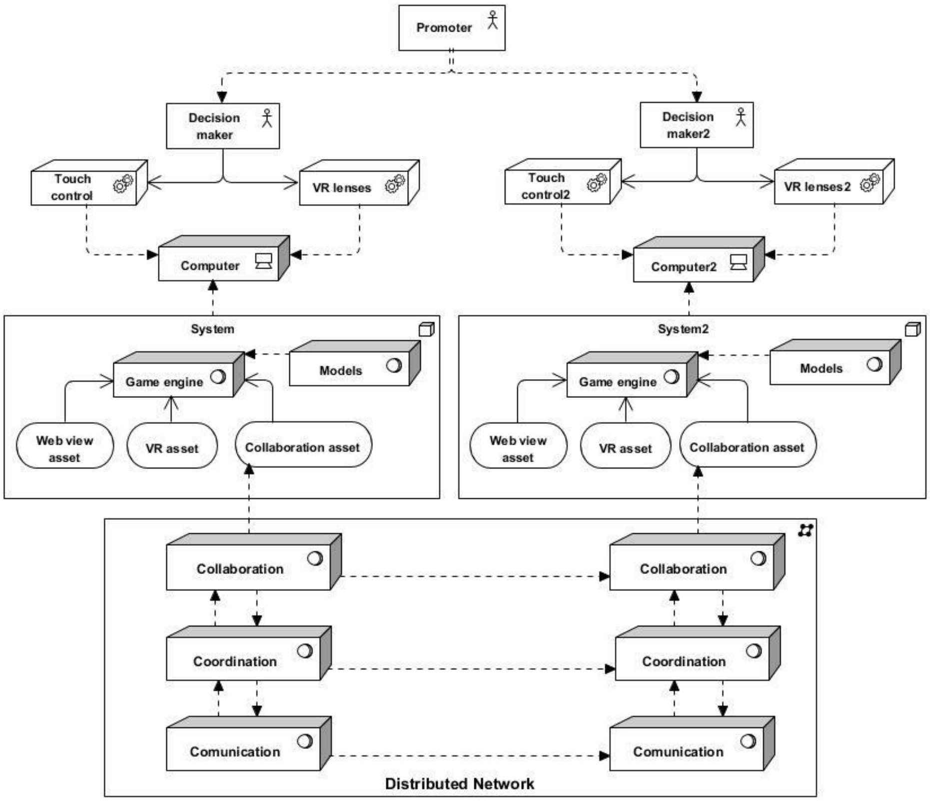

Figure 10: The proposed architecture of the multi-sensory environment for remote collaborative decision-making.

- **Promoter:** this actor is in charge of starting the system configurations, loading the model, creating the list of decision-makers who will participate, he must also invite the decision-makers and provide them with the files and details necessary to participate in the session.
- **Decision maker:** this actor is in charge of entering the decision-making session, he can visualize the virtual environment, he can also communicate with the other decision-makers in the session and modify the variables of the decision-making model that are worked into the session, finally, all decision-makers can agree that a consensus was reached and leave the session.
- **Touch control:** this device is used to interact with the buttons, it is also used to manipulate the variables presented by the model in the virtual environment
- **VR lenses:** this device is responsible for allowing the user to view the virtual environment and communicate with other decision-makers
- **Computer:** This device is the one that allows the connection between the touch control, the virtual reality helmet, and the multi-sensory system. Also, this is the one that provides the connection to the server for multi-user interaction.
- **System:** the system consists of several elements such as the game engine and models, as well as the connection to the network.
- **Models:** this element contains the models for data scenarios and decision-making in web view mode.
- **Game Engine:** This element contains the multi-sensory system that consumes the element of the model to generate its views and is responsible for connecting the system with the web view asset, the virtual reality

asset, and the collaboration asset.

- **Web view asset:** it is responsible for allowing the visualization and modification of the models within the multi-sensory environment
- **VR asset:** it is responsible for allowing the connection of virtual reality glasses within the multisensory environment, manages sight and movement within the multi-sensory environment as well as the microphone, if the glasses have it, for communication between decision-makers. In addition, it is responsible for allowing the connection of the touch control device within the multi-sensory environment, managing the feedback and the use of the touch control hand.
- **Collaborative asset:** is responsible for managing communication between decision-makers within the multisensory environment.
- **Distributed network:** it will be the network that will be used for communication, within the multi-sensory system, between decision-makers, it will be a client-server type network in which there are three layers: collaboration, coordination, and communication.
- **Collaboration:** it is the layer of the network responsible for the interactions between decision-makers.
- **Coordination:** it is the layer of the network in charge of cooperating and controlling what is sent to the other decision-makers.
- **Communication:** it is the layer of the network responsible for communication between decision-makers.

The proposed architecture offers great benefits such as facilitating the integration of multisensory environments with virtual reality environments, in a collaborative way that allows exploring evidence-based decision making. Another added benefit is allowing the integration of environments so that decision makers can interact immersively remotely in real time with virtual reality and touch control devices.

5.2. MVDC: Multi-sensory Virtual Decision-making Center

From the proposed architecture, MVDC is developed, which is a multi-sensory environment in which a Decision-Making Center is simulated in a virtual way, in which several decision-makers can interact in an multi-sensory immersive remote collaborative way in real-time.

The main functions that MVDC has are

- **Make a guest list:** the promoter must create a guest list with all the decision-makers who will participate in the session to be held.
- **Load models:** the developer is in charge of adding the necessary URLs in the corresponding CSV file to work with the model to be analyzed in the decision-making session.
- **Send an invitation to the session:** the promoter defines a date and time for the decision-making session and sends the necessary files and details to the other decision-makers so that they can join the session.
- **Load configurations:** the decision-maker must previously load all the configurations indicated by the developer in order to access the model and the room within the MVDC.
- **Enter session:** the decision-maker must connect to the server and choose the room in which the session will take place to be part of the decision-making session proposed by the promoter in MVDC. The other decision-

makers will be informed of the access of the new decision-makers in the session.

- **Modify Variable:** decision-makers will be able to see the complete model and will have the possibility of modifying the variables that are present in the model with the touch control and virtual keyboard, modifying a variable will update the model for all decision-makers within the session.
- **Exit the session:** decision-makers have the option to exit the session, this will inform the other decision-makers who are still in the session within the MVDC that someone has left the session and the decision-maker that has abandoned the session is disconnected from the session.

6. Case Study: a decision-making session with MVDC

According to the proposed architecture (AMVCD), the use of various hardware (touch control, VR headset, and computer) is presented, in addition to containing a system that is capable of interconnecting the hardware to use it in a collaborative virtual environment.

It is important that the configurations of the computer, the virtual machine, and the multi-sensory environment must have at least the minimum characteristics that make them all work together in the best way to take advantage of all the characteristics that you want to develop.

In this case, we work with computers capable of supporting the minimum system requirements of Unity3D [27] and SteamVR [28], as well as the minimum system requirements for each virtual machine that was used, in this case, Oculus Rift [29] and HTC VIVE [30]. In addition, all Unity assets deployed in the multisensory environment are compatible with each other, as well as with SteamVR and the virtual machine used.

For the development of the case study and the experimentation, the implementation of MVDC is presented, which is an environment created from AMVCD under the Unity3D development platform in which multi-sensory collaborative decision-making sessions can be carried out. MVDC presents the implementation of the connectivity of the different hardware per user, as well as the network connectivity of all the users to work collaboratively, considering that the graphic rendering processing and the physical simulation are performed by Unity3D.

To start the simulation, the touch controls, and VR headset must first have been recognized by the SteamVR program and the headset microphone must be set to 48000Hz in the sound input settings of the computer. When starting the simulation, all hardware equipment starts communication with each other automatically, through the use of Unity3D and SteamVR, allowing the reading of positions and interactions of all user devices, then for network connectivity with other users and being able to interact with them, the Photon engine [31] is used, which allows the client-server communication of the MVDC through Photon PUN and voice communication through Photon Voice, and for the visualization and modification of the model in the virtual browser web view the embedded browser asset was used [32], all of them work well with the Unity3D and SteamVR configurations used for environment creation, so they were used instead of other communication resources that exist.

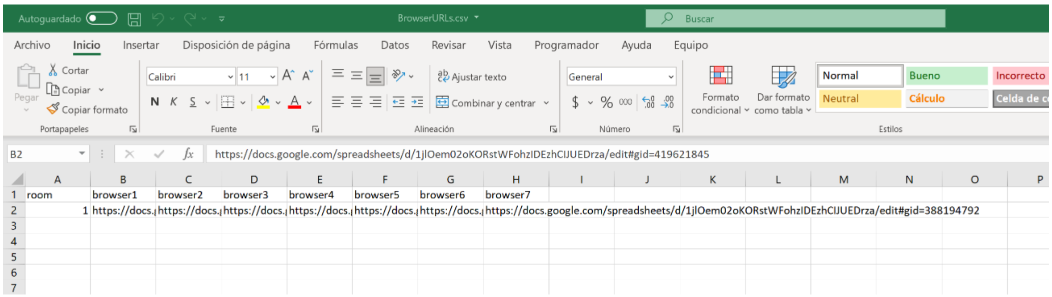

Figure 11: CSV configuration file.

Figure 12: Placing the Touch controllers and VR headset. On the left Oculus Rift Headset [29], on the right HTC VIVE Pro Headset [30].

To access the session, the decision-maker must have preloaded the CSV configuration file with the room number and model URLs (Figure 11), then the virtual reality equipment must be put on (Figure 12), and the MVDC environment started. Once the environment is open, you must press the connection button (Figure 13.a) that will take you to the lobby (Figure 13.b), where you can access the room indicated by the promoter in your invitation and enter the decision-making session where will show the model to be analyzed (Figure 14), which can be modified and communicated with other decision-makers by voice (Figure 15).

a) b)

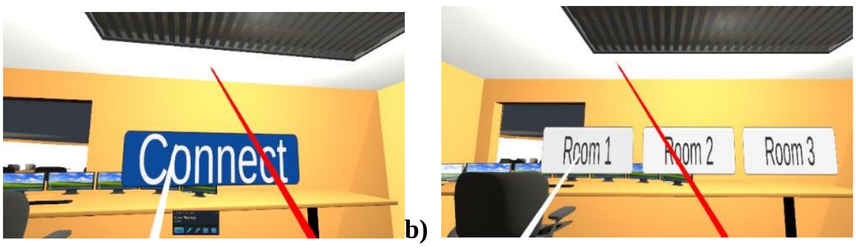

Figure 13: View of the initial scene and lobby of the MVDC.

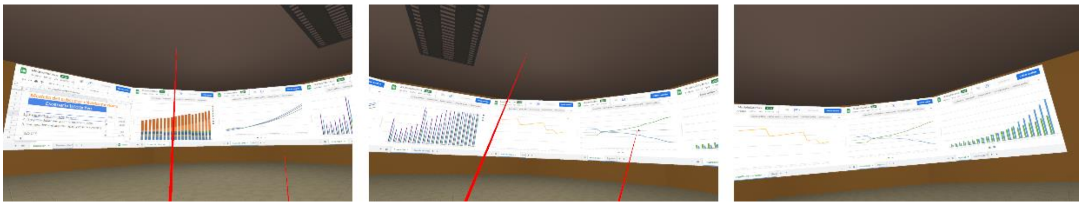

Figure 14: View of the model in the MVDC decision-making room.

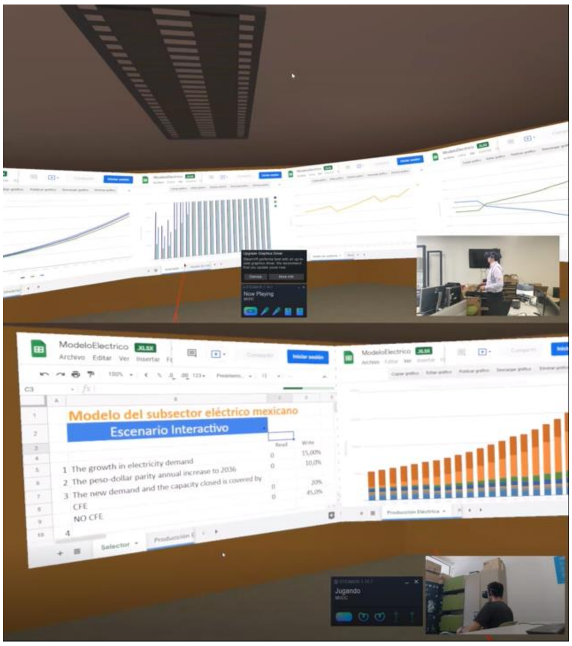

Figure 15: View of the multi-user interaction in the MVDC decision-making room.

In addition, for a virtual decision-making session to take place in general, a scenario is needed in which users can interact, so in this case, a real scenario that resembles a Decision-Making Center was created, in which the physical interactions and the behavior of the graphical components are controlled by Unity3D respecting the traditional laws of physics.

7. Experimental design and test

The purpose of this experiment is to identify if the user experience in the decision-making process can be improved in terms of remote interaction, communication, and presence, through the use of the Multi-sensory Virtual Decision-Making Center, which is the integration of a multi-sensory, remote, collaborative, and immersive environment in real-time, provided by a virtual environment for the management of remote decision-making scenarios.

Using the multisensory environment described previously, an experiment was developed in which a decision-making session is presented in which the TEC-SENER electric model is used to be analyzed [33].

The experimentation process was carried out to test the multi-sensory environment, 11 experts in fields related to computer engineering, the energy sector, decision-making, and virtual reality participated.

And the experiment was carried out in two modalities: in person using the virtual reality equipment and remotely through video calls where a context of the research was presented and the functions of the environment were explained with the visual aid of a video where a multi-user decision-making session is carried out with the multi-sensory environment.

After the experimentation process as part of the analysis process, eight questions were asked to verify if the multi-sensory environment presents benefits to the user experience by participating in collaborative decision making sessions in a multi-sensory, immersive, remote manner in real-time. The questions asked were the following:

Q1. Visualization of the environment of the Multi-sensory Virtual Decision-Making Center improves the user experience

Q2. Communication between decision-makers in the Multi-sensory Virtual Decision-Making Center improves the user experience

Q3. Interaction between decision-makers in the Multi-sensory Virtual Decision-Making Center improves the user experience

Q4. Viewing data from the model within the Multi-sensory Virtual Decision-Making Center has advantages over a normal Decision-Making Center model

Q5. Manipulation of model data within the Multi-sensory Virtual Decision-Making Center has advantages over a normal Model of a Decision-Making Center

Q6. The Multi-sensory Virtual Decision-Making Center facilitates collaboration between decision-makers in an immersive way in real-time

Q7. The Multi-sensory Virtual Decision-Making Center has the characteristics of a Decision-Making

Q8. The Multi-sensory Virtual Decision-Making Center is a good alternative to physical Decision-Making Centers

8. Results and Discussion

Now to give an answer to the research question and validate the hypothesis based on the results obtained from the questions asked to the experimenters, the results were reviewed in terms of remote collaboration in real-time, multi-sensory interaction, and functionality as an alternative to a Decision-Making Center (Figure 14).

In terms of remote collaboration in real-time, based on the answers to questions Q2, Q3, and Q6, 27.3% of the experimenters agreed and 66.7% of them expressed their full agreement, making a total of the 94% agreement by the experimenters, thus indicating that the MVDC environment is a great tool for remote collaboration in real-time at the level of communication and immersive multi-user interaction in real-time, providing decision-makers with an improvement in the user experience at the level of communication and remote interaction in real-time.

Then, in terms of multi-sensory interaction, based on the answers to questions Q1, Q4, and Q5, it can be identified that 24.3% of the experimenters expressed agreement and 60.6% of them expressed total agreement, making a total of 84.9% of the experimenters agree that the MVDC environment has characteristics and facilities to interact with other decision-makers in a multi-sensory way and provides benefits to the user experience when participating in sessions collaborative remote decision making in real-time.

Finally, based on the answers to questions Q7 and Q8, it can be seen that 4.5% of the experimenters agree, and almost all the experimenters, 95.5% of them, totally agree, so that 100 % of the experimenters agree that the MVDC environment has the characteristics and benefits that the Decision-Making Centers have and in addition, the experimenters expressed that the MVDC environment also has additional characteristics that do not exist in a Decision-Making Center, therefore, the MVDC environment is a great alternative to carry out remote collaborative decision-making sessions in real-time.

Achieving as a result of this answering the research question and validating the hypothesis, the MVDC environment is a great remote alternative to Decision-Making Centers, especially in periods of confinement and when people are at a distance, and that it has characteristics and functionalities that provide a collaborative, remote, multi-sensory, immersive, synchronous relationship in real-time allowing decision-makers to have better interaction, remote collaborative in real-time, maintaining the relationship between decision-makers providing a new way of interacting between decision-makers and facilitating decision-making sessions, as well as improving the user experience in the decision-making process. Thanks to these results, it can be said that a positive response to the research question was obtained and the validity of the hypothesis was demonstrated positively.

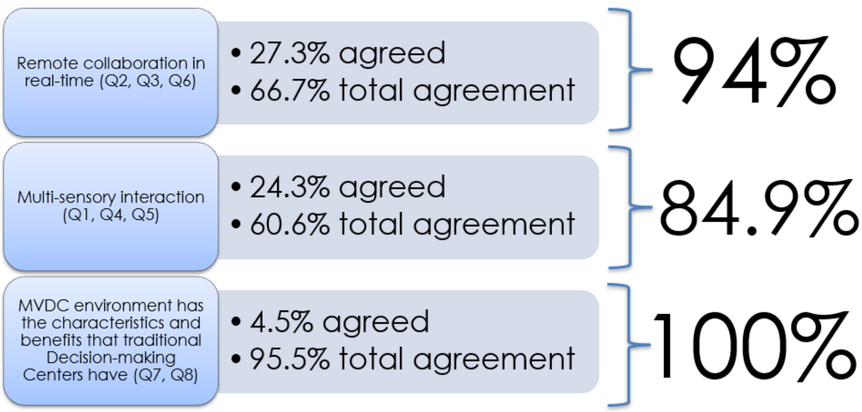

Figure 14: Results obtained from the questions asked in the experimentation process.

Along with this, we can mention the technological evolution and the popularity that virtual reality technologies will have with the creation of the metaverse, which seeks to integrate multi-sensory characteristics of virtual reality for immersive interaction, which will change the rules of the game. The characteristics that virtual reality offers can be used in diverse areas, with the use of infinite screens, or with the creation of a more real sense of the presence of the virtual environment where people can be more productive and collaborative than ever before. With the metaverse, it is intended that in the future people can work in a more fluid way remotely in real-time allowing them to work with colleagues who are in different places in a more efficient way [34].

9. Conclusions and Future work

In this work, an investigation was carried out on the Decision-Making Centers and their main characteristics. From the research, the need arises to create a Virtual Multi-sensory Decision-Making Center in which remote decision-making sessions can be carried out in an immersive, collaborative, and real-time way to seek to facilitate the use of the Decision-Making Centers. Make decisions remotely without losing your sense of presence. From this premise, an architecture capable of supporting the characteristics of a Decision-Making Center is created in a new way where the decision-making process can be carried out through the help of virtual reality and related devices. that allow collaborative multisensory immersion where multiple decision-makers can participate remotely in real-time. Along with the architecture, an immersive, collaborative and remote multisensory environment was implemented, which resembles the Decision-Making Centers, adding additional characteristics allowed by the use of virtual reality.

Also, through the process of reviewing related works, experimentation, and analysis of the results obtained, it was possible to respond positively to the research question, and positively validate the hypothesis, showing that the architecture created and the multi-sensory environment developed Based on this architecture, it provides benefits to the user experience through a synchronous multi-sensory relationship that provides benefits to decision-makers by participating in immersive collaborative remote decision-making sessions in real-time.

Along with the above, it can be indicated that decision-makers feel that they are in a Decision Making Center where they can carry out remote collaborative decision-making sessions in real-time, they can zoom in on the model views to see more closely the values of this, as well as edit the allowed variables of the model and that all decision-makers are notified and can see the changes that occur in the decision-making session in real-time while they are immersed in a Multi-sensory Virtual Decision-Making Center. Thus, providing an improvement in the user experience by conducting decision-making sessions remotely in real-time. In addition, the multi-sensory environment has the ability to support three decision-making sessions happening at the same time independently, obtaining a plus over a Decision-Making Center, along with this it is worth mentioning that the required space and investment costs and maintenance are less with obtaining a Multi-sensory Virtual Decision-Making Center compared to a Decision-Making Center, this being one of the many benefits found when creating and using a Multi-sensory Virtual Decision-Making Center.

It can be said that thanks to this work in the future the remote decision-making sessions will have a new perspective as well as a greater sense of presence in real-time than in the past thanks to the virtual multi-sensory immersive collaborative remote environment in time real that unfolded.

As part of the future work that could be developed from the proposed architecture and the multi-sensory environment, it can be mentioned that one could try to add the sense of touch in another way, such as adding haptic feedback devices for handling model data. Also can try to work with the metaverse that is about to happen, trying to develop collaborative multi-sensory immersive tools in real-time to carry out remote sessions that are increasingly better in the sense of collaboration and presence. According to OculusVR [34], there will be an increase in the use of multipurpose virtual reality devices that can be used to play, work, surf the web, personal use, among others. It's about making virtual reality as user-friendly and popular as smartphones and laptops are today, which is why virtual reality companies are evolving to improve the experience and get users a better experience.

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