

IMPLEMENTATION OF A VIRTUAL REALITY COLLABORATIVE PLATFORM FOR INDUSTRY 4.0 OFFICES

Gicu Călin DEAC^{1*}, Crina Narcisa GEORGESCU²,
 Cicerone Laurențiu POPA³, Costel Emil COTET⁴

¹⁾ PhD student, Robots and Manufacturing Systems, University Politehnica of Bucharest, Bucharest, Romania

²⁾ PhD student, Robots and Manufacturing Systems, University Politehnica of Bucharest, Bucharest, Romania

³⁾ Associate Prof., Ph.D., Robots and Manufacturing Systems, University Politehnica of Bucharest, Bucharest, Romania

⁴⁾ Prof., PhD, Robots and Manufacturing Systems, University Politehnica of Bucharest, Bucharest, Romania

Abstract: This paper describes some results of authors' research for developing a Virtual Reality collaborative platform for remote teams able to work in a fully equipped environment that resemble as close as possible a real office. The platform allows real-time interaction between user's avatars, using high quality surround audio messaging, gestures and physics and includes a large number of tools for collaborative working such as: remote desktop, videoconference, white-board, screen sharing, slide presenter, synchronized video player, web applications, individual and group teleporting, animated 3D model viewer, advanced user management, IoT telemetry data visualization, smart factory digital twin integration. The platform was implemented for few business cases for virtual offices, conferences, e-Learning, trade shows and as a virtual reality interface for a digital tween.

Key words: Industry 4.0, virtual reality, collaborative working, IoT, smart factory, digital twin.

1. INTRODUCTION

In the context of a Smart Factory and of Industry 4.0, virtual reality (VR) as an interface for the digital twin represent a key technology for design, simulation, training, and operation of cyber-physical systems.

Telemetry data captured from industrial machines by different sensors and process computers can be stored on the cloud and can be used to drive the virtual twin machines created in VR. In this way, remote operators can access real-time data about machine status, maintenance, technical libraries and can trigger remote commands or adjust the operation parameters of machines [1].

Boschert and Rosen [2] define the digital twin as a linked collection of digital artefacts that evolves with the real system and acts as a process-monitoring tool.

Virtual reality can be used also for training on machines and make possible to simulate different working scenarios in a safe way. Matsas and Vosniakos [3] created a training tool using virtual reality to study human-robotic arm interactions, allowing the operator to understand how to safely behave during human-machine collaboration.

Mohamed-Amine et al [4] propose a software for simulation of production flows in a virtual environment in real time and highlighted the main advantages of using VR to the manufacturing processes in a lean environment.

Regarding the virtual reality, Jerald Jason [5] specify that VR is communication and classify this aspect in direct communication, as a direct transfer of energy between two entities, structural communication being the physics of the world, visceral communication as the language of automatic emotion and primal behavior and indirect communication made by an intermediary (written language, signs, interfaces, speech recognition).

As one can see from the Dale's cone of experience, (Fig. 1) virtual reality simulations can enhance understanding by using all degree of abstraction, being a powerful tool for training and communication.

So far, a multitude of VR implementations have been created for visualizing industrial processes, simulations, or training, but most of them are local, single-user simulations. In this research a server-client application for several remote users is proposed, which can access the same virtual environment and interact with each other and using a multitude of integrated tools to work collaboratively like in a real office. This application was created to be used both in VR mode, wearing HMD (head mounted display) and trackers, but also in desktop

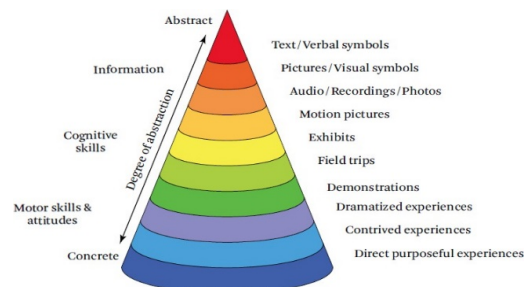


Fig. 1. The cone of experience (adapted from Dale [6]).

* Corresponding author: Splaiul Independentei nr. 313 Sector 6,
 Bucuresti, Romania
 Tel.: 0741 073 007
 Fax: 0344080800
 E-mail address: george.deac@impromedia.ro

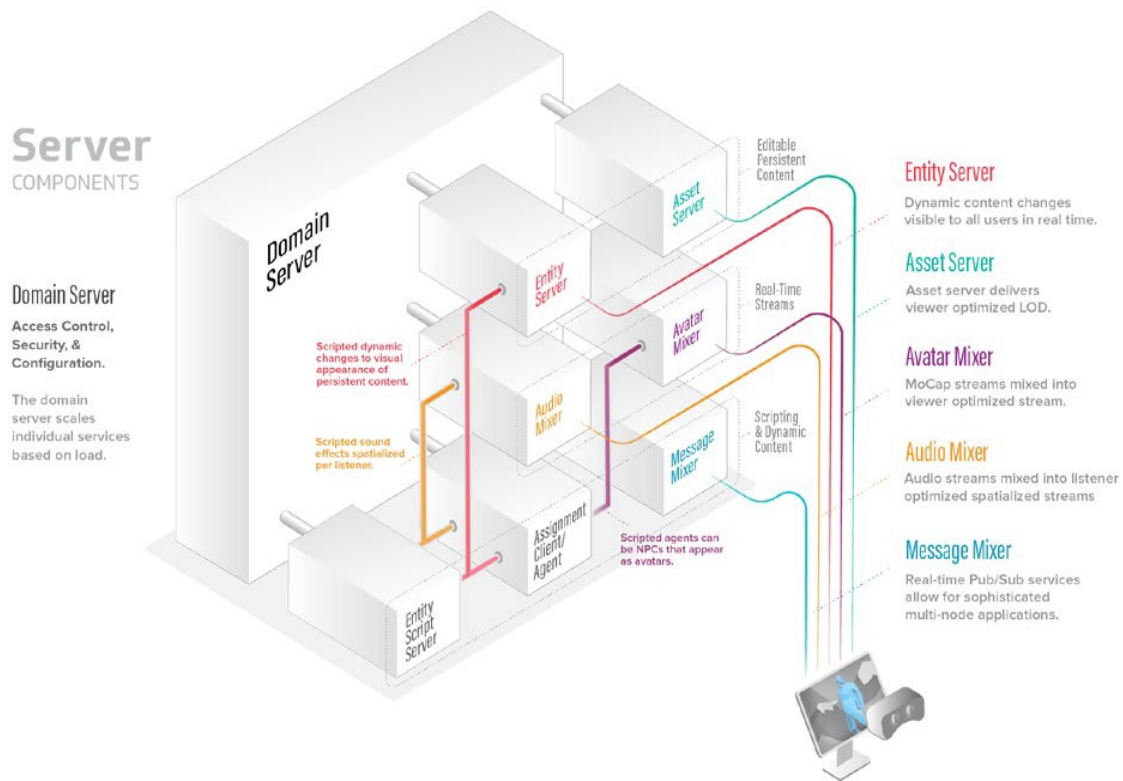


Fig. 2. VR application server components.

mode on any device, in this way it can be used by as many users as possible.

During the implementation of this platform, several challenges occurred, caused especially by the limited hardware resources of most users as well as the strict network security policies of companies.

2. 8AGORA PLATFORM

8agora platform was developed with an architecture consisting in interconnected components that communicate to each other (Fig. 2):

- Client interface runs on user's computer and allow to connect and attend live simulations.
- The domain server is the main component that hosts the content such as 3D models, scripts, audio files and manages the settings for audio attenuation, audio spatialization, codecs, zones, user permissions, maximum number of concurrent users and backup policies.
- The Global Services are maintained by the domain server and allow users to sign in and navigate to different places.

2.1. Server Stack

The domain server is the heart of the stack that creates jobs for different assignment clients and provide both IP addresses and ports for each assignment client to the connected interface clients.

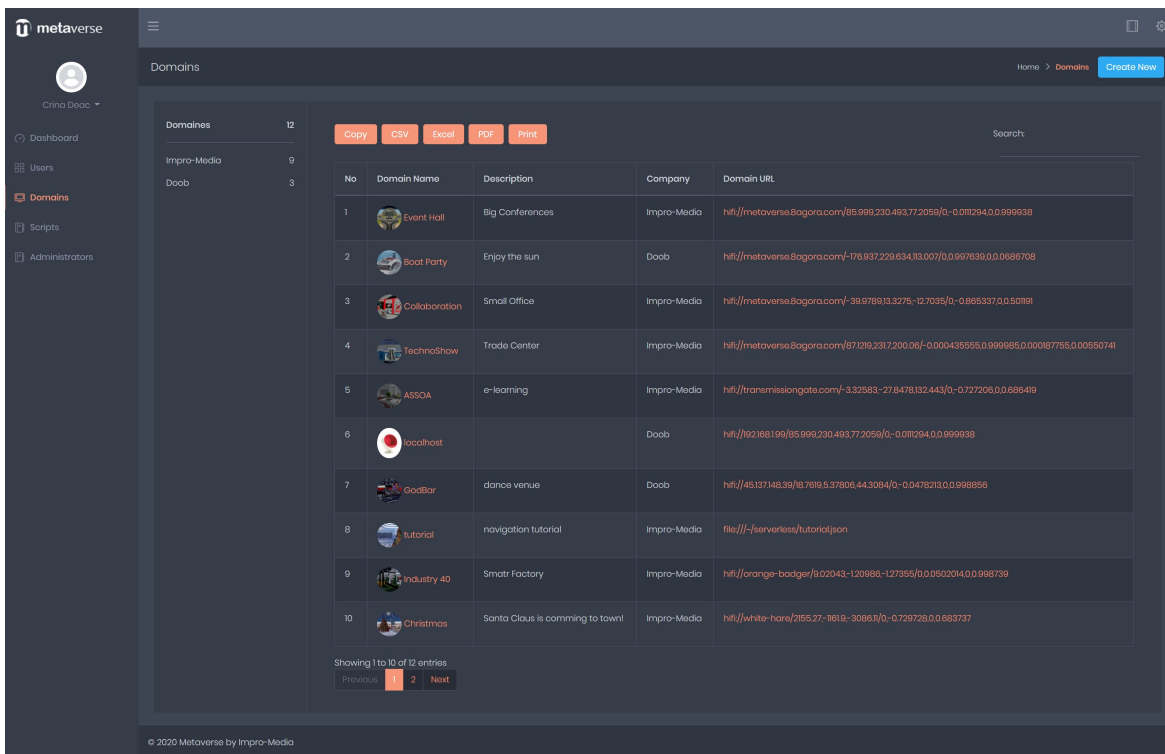
2.2. Assignment Clients

The Assignment Clients are responsible for different functionalities of the domain. They work together and

communicate in direct way with the connected interface clients. These six assignment clients are:

- Avatar Mixer-it manages the movement and animation of avatars in any domain. It keeps track of location, model of the wearing avatar, and how users are moving inside a domain. It tracks how a user are moving head and hands while wearing a Head Mounted Display (HMD) and controllers and broadcast this telemetry data to all users.
- Audio Mixer-it is a surround audio mixer that combine all sounds, whether it is voice or environmental. The Audio mixer are spatializing the sound and amplify or attenuate the sound based on avatar position and orientation relative to the audio source.
- Entity Server-manages all the entities and their specific properties in a domain, like name, description position, rotation, parenting, and attached scripts.
- Asset Server -Provides for download to the clients copies of the entities used in the domain simulation.
- Agent - Executes the JavaScript programs created by the users.
- Messages Mixer - Provides channels of communication between the scripts running in different programs in the domain.

The architecture is scalable and flexible. It is possible to install assignment clients over multiple servers, or to split each function on multiple assignment components, installed on different servers. For instance, we can use multiple audio mixers assignment clients to mix the sound for different geographic regions of the domain.



The screenshot shows the 'Domains' management interface. On the left is a sidebar with navigation options: Dashboard, Users, Domains (selected), Scripts, and Administrators. The main area displays a table of domains with columns for No., Domain Name, Description, Company, and Domain URL. Above the table are action buttons for Copy, CSV, Excel, PDF, and Print. A search bar is located in the top right of the table area. The table contains 10 entries, with the first two rows highlighted in blue. At the bottom, there is a pagination control showing 'Showing 1 to 10 of 12 entries' and 'Previous', '1', '2', 'Next' buttons.

No.	Domain Name	Description	Company	Domain URL
1	Event Hall	Big Conferences	Impro-Media	http://metaverse.Bagora.com/85.999.230.493/77.2059/0-0.001294.0.0.999938
2	Boat Party	Enjoy the sun	Doob	http://metaverse.Bagora.com/-176.937.229.634/83.007/0.0.997639.0.0.0686708
3	Collaboration	Small Office	Impro-Media	http://metaverse.Bagora.com/-39.97699/13.3275-12.7035/0-0.866337.0.0.80891
4	TechnoShow	Trade Center	Impro-Media	http://metaverse.Bagora.com/87.1218.2317.200.06/-0.000435555.0.999985.0.000187755.0.0055074
5	ASSOA	e-learning	Impro-Media	http://transmissiongate.com/-3.32583-27.8478/132.443/0-0.727205.0.0.686419
6	localhost		Doob	http://192.168.1.99/85.999.230.493/77.2059/0-0.001294.0.0.999938
7	GodBar	dance venue	Doob	http://45.137.148.39/18.7619.5.37806.44.3064/0-0.0478213.0.0.998856
8	tutorial	navigation tutorial	Impro-Media	file:///serverless/tutorial.json
9	Industry 4.0	Smart Factory	Impro-Media	http://orange-badger/9.02043-1.20986-1.27355/0.0.0502034.0.0.998739
10	Christmas	Santa Claus is coming to town!	Impro-Media	http://white-hare/2165.27-1819-3086/0/0-0.729728.0.0.683737

Fig. 3. Identity manager web interface.

2.3. Global Services

Bagora Global Services are providing identity tokens for domains and users and can be configured using the Identity manager application.

The identity manager runs on a central server and allows web-based requests from different domains and users. It stores in a Mongo database in json format all the details regarding the domains and users. Using a web interface (Fig. 3) the administrators can add new domains, their web address or IP, ports and entering points coordinates (x, y, z) for each place. In the same interface can be defined different scripts, their web address and name.

For each user, can be specified a list of whitelisted domains to attend (these domains will be automated displayed in the GOTO application), a list of scripts to run, name, email, picture, and avatar model location. In this way we have a flexible way to manage each user rights. On user management interface we have also a checkbox to assign the status as guest. If a user has this status assigned, the client interface will be configured to expose a small number of options, menus, and features, to be simpler to use. The identity application allows to manage domains and users on different groups (companies), for instance based on the client interface version will know on which company group to assign a user identity when the account is created on signup.

The administrator accounts can be created with global or company level of access.

When a new domain server is installed, from the web configuration interface which runs as a service on the same machine, on port 40100 a token is requested to the identity manager to be enlisted. After the token is

received, the server can be accessed by all the whitelisted users on that specific domain. From the same interface, can be configured and generated backups, in automatic or manual mode, can be uploaded the domain content and specified different domain parameters like user rights, audio attenuation, maximum concurrent users, audio codecs and more.

The content of a domain can be managed and edited directly from the client interface if the authenticated user has editing rights on the connected domain. From the editing interface (Fig. 4), the user can import 3D models, create 3D shapes, particles, web entities, zones, lights, texts, and materials. The 3D models can be imported in FBX, OBJ or GLTF format and can include baked animation. The models must be textured using PBR (physical based materials). To reduce the drawcalls (number of calls to the graphics API to draw objects), and improve the user experience, for complex objects it is better to use atlas textures and create low polygonal meshes. The details on the surfaces can be improved using normal maps.

The application includes a powerful physics engine to run simulations, based on Bullet (<https://pybullet.org>), which simulates collision detection, soft and rigid body dynamics. For each object can be defined physical parameters from the editing interface such as: grabbable, triggerable, cloneable, collides, dynamic, linear velocity, linear damping, angular velocity, angular damping, bounciness, friction, density, and gravity.

The objects can be locked/unlocked, hidden/unhidden, parented to a different object, and each entity can have assigned scripts and server-side scripts and can hold in json format different user preferences.

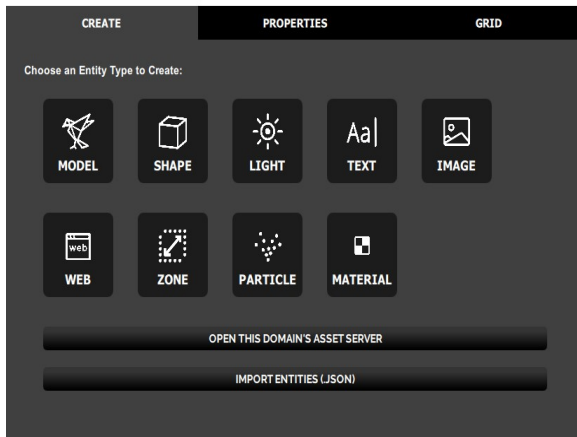


Fig. 4. Editing interface.



a



b



c



d

Fig. 5. Views from different zones created for different applications: a – conference zone 1; a – conference zone 2; c – virtual office zone; d – smart factory zone.

All kind of objects (3D models, images, java-scripts) can be hosted externally on different web servers and included in the simulation as a link or can be uploaded and stored on the domain server ATP (entity library). The main advantage to store the assets on an external server is that you can use the same library on multiple domains for different simulations, the assets stored on the ATP, being visible only in that specific domain.

The application was developed in C++ and have a large API library exposed to JavaScript, in this way we have a flexible and easy to extend platform. Supported script types are: Interface Scripts, Client Entity Scripts, Avatar Scripts, Server Entity Scripts, Assignment Client Scripts. The Script namespace let users to connect callbacks from client to script, such as functionality that is dependent on time (`Script.setTimeout`, `Script.update`, `Script.setInterval`, etc), connect paths relatively to assets (`Script.resolvePath`), refer to other scripts (`Script.require`, `Script.include`), or connect functions to events which occur when the script is turned off (`Script.scriptEnding`).

Figures 5,a – 5,d show some views from different domain zones created for different applications like virtual office, conference, and smart factory digital twin. Users can "walk" or "fly" from one zone to another or can use the GOTO application interface to select a specific zone to be "teleported".

3. DEVELOPED APPLICATIONS

To improve the user experience and use the platform effectively for collaboration, and to include features related to Industry 4.0, the platform was expanded with some applications and scripts.

3.1. GOTO application

This application can be started from client interface, by pressing the GOTO button. When a user starts the client application, is redirected to a training zone, where information regarding the controls, navigation and functionalities are presented. If the user is not logged in, it will not be able to visit any domain. After authentication on the platform, with his credential, based on the whitelisted domains defined by the identity manager administrators, the GOTO menu will be populated with links to all these domains. By clicking on a link, the user is teleported to the specific location of that domain.

The GOTO application includes other functionalities like enlisting users to a company, loading custom scripts for each user and loading the personal avatar of user. The application checks continuously the authentication status of the user and if the user is logged in, will request from the identity manager application based on username, all the specific data for the user like whitelisted domains, the list of custom scripts, the user real name, if is guest, avatar mesh location. When the user logs out, the application will remove the domain links, scripts, and avatar, in which case the user will wear a generic one. The application also hides the menus from client interface application if the user is marked as guest.

3.2. Group teleport application

This application is composed by two different scripts, one loaded by the moderator and other client script loaded automatically for all other users by the identity manager application. The moderator script has an interface where are defined different locations from a domain or from other domains. The application calculates, based on user number and entry point coordinates the individual locations for each user to teleport them in proximity of each other, not in the same spot. When the moderator selects a location from the menu, user specific messages containing individual locations is sent using the Messages Server to all the users running the teleport client application and users will be teleported on that location. The application has a checkbox to enable / disable moderator teleportation, based on this setting the moderator can be or not teleported at the same time with other users. This application is useful on guided tours or on different working scenarios when users need to be transported at the same time to a different location.

3.3. Avatar expression application

When users are wearing HMD and controllers, all movements from the real world are tracked and reflected on the avatar. If the application is running on desktop mode and the avatar is driven by the WASD keys and mouse, the avatar has limited expressiveness. To solve this limitation, the avatar expression application includes few buttons with different functionalities that can be triggered by mouse click. The user can select approval, disapproval, rise the hand, clapping, point at, and emoticons. The point at option, will drive the dominant hand of the avatar using the mouse to point to a specific object or avatar. A red target spot visible by all avatars will be also displayed.

3.4. Name tags application

When name tags option is checked, a text box containing the real name of user is rendered over each avatar head.

3.5. Audio focus application

The platform has an immersive surround audio mixer, based on relative positions, orientation, and a predefined sound attenuation all the sounds, coming by avatar voice or from the environment being mixed. If the avatars are at big distances, they cannot hear each other. Also, if in the same domain are present a big number of avatars, all talking, it is difficult to have decent conversations only with few of them. For this reason, we have developed the audio focus application, that allows to create a list of users by clicking on their avatars and hear unattenuated voices only from selected avatars. The user has the option to add, delete users to the list and enable/disable audio focus option, by triggering a button from toolbar menu.

3.6. Remote desktop application

This application use VNC server (Virtual Network Computing) installed on a remote computer and a Node.js WebSocket application to allow remote desktop

connections directly from VR, using web entities. VNC is a graphical desktop-sharing system that uses the Remote Frame Buffer protocol (RFB) to remotely control another computer. It transmits the keyboard and mouse events from one computer to another, relaying the graphical screen updates back in the other direction, over a network. In this way it is possible to have virtual computer screens embedded in simulation. Using this virtual computer, users can work directly on virtual environment. This computer can run any operating system and applications and can be used for daily working on CAD/CAM applications, office, ERP, CRM, or can be used for presentation purposes. To make available the audio from the remote computer, a low latency WebRTC audio streaming script was included. The remote screens based on user rights or permission flags can have two functionalities: editing or view only. If the editing functionality is enabled, the user can access the remote computer using keyboard and mouse, otherwise it can only see the screen, without any interactions.

3.7. Whiteboard application

This application creates a 3D whiteboard in the 3D environment that can be used by multiple users at the same time, for drawing and presentation purposes. Users can choose different colors of the pen or use the eraser.

3.8. Presenter application

This application includes multiple functionalities like slideshow, video sync, polls, web content, live camera streaming, chat, teleprompter (Fig. 6). The slideshow module allows users to upload slide images on the asset server and present them sequentially using next/previous buttons to one or multiple big screens. When the presenter switches the slides, a message is sent to the big screens to load the same slide. The video sync module is created to facilitate the collaborative video playing.

Because users are running the application as a client, each one has his own video player loaded. The video sync module is created to facilitate the collaborative video playing. Because users are running the application as a client, each one has his own video player loaded. To synchronize the frames of the video we have developed this module that capture users' interactions with the video player (play, pause, fast forward, jump to a specific frame) and send this information to all video players using the Message mixer, in this way all video instances for each player being in sync and playing the same frame of the video. The live camera streaming module is used for different show cases, to present a product or object or to display the real-life image of the presenter. This was developed using low latency WebRTC and HTML and runs on a web entity.

The presenter screen also includes a text chat application that displays messages from users like questions or requests, that are displayed to the presenter. This text chat can be interconnected with the automatic translation application. The teleprompter module allows editing or copy a presentation text, adjust screen size and playing speed, being a useful tool for professional presentations.



Fig. 6. Presenter application dashboard.

3.9. Automatic translation application

This application was built using WebRTC and Google translation API and can translate in real time the voice of presenter using Speech to text from / to almost 200 different languages. In this way each user will be able to see a translated transcription of what presenter are saying in the text chat application using his preferred language.

3.10. Video conference application

The video conference application can be displayed in an overlay web window or on an entity window for big audience and allows direct audio-video communication from the virtual environment to outside world, or between different domains or locations from the virtual environment. User can select a real web camera and microphone or a virtual camera that will broadcast the avatar and virtual environment. The video conference application also includes a text chat, a screen sharing option and a recorded video broadcast option.

3.11. Live streaming application

This application allows to capture what an avatar is seeing or to get images provided by different virtual

cameras to stream live with low latency the event. We have used Wowza Streaming Engine installed on a dedicated server to be able to reach big audiences.

3.12. Automated camera application

This application creates virtual cameras in the environment and automatically follow the presenter avatar, capture the image, and display the projections on big screens. This application can be used in combination with the video conference application, or with the live streaming application.

3.13. 3D models and CAD viewer

This application allows the upload or link-based input of various 3D models (including animations) to be presented in the virtual environment. This application can be used to showcase products, designs, and can trigger based on a script different animation and to adjust the start frame, end frame, number of frames / second to play the animation.

3.14. IoT interface application

This application allows real-time data visualization of telemetry from sensors and to drive animations of virtual machines based on this data. The application uses a configurable web-based middleware that allows to use different API from various IoT platforms or to configure MQTT communication channels with distributed IoT devices. The data captured in real-time by the middleware are exposed in JSON format to the integrated IoT application and can be displayed inside the virtual world using 3D web entities, text entities or can drive different animations or trigger different actions.

Using this interface, it is easy to script actions on user interactions, for example, when a user click on a machine component, information regarding the sensors values like temperature, vibrations on axes, maintenance information and more can be displayed. In the case of virtual machines, rotations, positions of different components can be easily adjusted to reflect the real machines. This integration creates the possibility to use the VR application to develop digital twins and visualize the entire factory in collaborative mode, with distributed teams, being a valuable alternative to the classical 2d application interface screens.

4. PLATFORM IMPLEMENTATION USE CASE

The platform was already implemented for few use cases like conferences (for VRARA), virtual exhibitions (MedAcademy, TechnoShow), e-Learning (Alice Springs School of the Air from Australia) and for collaborative working and virtual offices for few companies of Deutsche Telekom Group.

In the case of T-Systems Virtual Innovation Center they needed a virtual office for meetings and presentations of their tech tools and services. The implementation and hardware devices costs were not an issue and they are using high-end computers with HMD and controllers. The main challenge stated by them was regarding the invited clients. This various business clients, from around the world, need to attend their events and most of them don't have powerful enough computers, maybe are travelling and use only mobile devices, also most of the companies' network security policies are firewalling most of ports, allowing only ports 80 and 443 for web browsing. The 8agora application need various ports both TCP and UDP for all distributed services, in the case of restricted networks being unusable.

For this case we have chosen to install the client interface application on GPU servers in cloud. We have started with an image containing the Windows Server operating system, the interface client application and a GPU accelerated web remote desktop application with bidirectional audio. Based on this image we can instantiate on request any number of virtual machines. The GPU machines were provided by the OTC (Open Telekom Cloud), but can be also used services from AWS, Azure or Alibaba or other cloud providers. For each client we need to instantiate a GPU virtual machine based on the initial image, get the web address of the web remote application, and send this link to the client. This seems to be an easy task, but for day-to-day activity, or in

Fig. 7. Booking interface.

the case of big events, with many users this process needed to be automated.

For this purpose, the Avatar booking application was developed, which is a calendar-based application that allows to create events on a specific date, with start and ending time, instantiate the GPU virtual machines, generate links with authentication tokens for users, and send the invitations by email to the clients. By clicking on the invitation link from email, the client will be redirected to the GPU machine virtual desktop web address and can access the client interface application installed there from any device (computer, tablet, smart phone) using a web browser. In the case that the user is accessing the application from a mobile device (tablet or phone) a D-pad navigation script is started and the user can use touch controls for navigation inside the virtual platform. The authentication token for remote is available only on the scheduled period, in this way being able to use the same GPU machine for many users at different moments of the day, based on the calendar application.

For the best user experience in the case of cloud implementations, it is important to deploy the GPU virtual machines in locations close to the user, in this way the latency can be reduced, and the responsiveness of controls increased. Also, the audio messaging will have in this case a smallest delay.

The cloud implementation on various devices was tested by using different internet connections and the experience was great even on 4G connection. Over the 5G connection the experience will be even great because of the low latency of the technology.

After a period of using of the cloud implementation the clients were asked to evaluate the experience and we have concluded based on the Fig. 8 that the platform performs well.

The satisfaction study was performed on 180 clients, from around the world, using different internet connections and devices.

We have conducted the survey on few topics:



Fig. 8. Satisfaction evaluation.

- Onboarding experience (how users are connected to a specific domain on the platform).
- Piloting experience of your avatar (driving the avatar in VR using the HMD and controllers or on desktop mode using the keys and mouse, the game controller or D-pad touch screen for mobile devices).
- Impression of the virtual space.
- Audio quality (clarity, latency, spatiality).
- Visual quality (clarity, smoothness, latency).
- Capabilities to present and display content (slides, video, web content, 3d models).
- Capabilities to interact, collaborate & exchange.
- Handling of presentation controls for speakers.

The evaluation was made on a scale from 10 to 1 (10 for dissatisfied and 1 for absolutely satisfied).

From their inputs we have concluded that we need to do improvements for the user interaction and personal data exchange and for the avatar driving system on desktop mode usage. The onboarding experience must be also improved by finding a way to better support the user to be familiarized with controls and application interface.

5. CONCLUSION AND FUTURE WORK

By using the 8agora virtual reality collaborative platform extended with developed applications we have succeeded to support teamwork and different use case scenarios for distributed teams and clients by offering a solid alternative for collaboration even on pandemic crisis. The interaction, the sense of presence and the tools embedded into the platform give a better experience and

effectiveness for distributed teams, in comparison with existing videoconference applications.

As future research we will implement different other use case scenarios and we will develop more integrated tools. Also, we will improve the avatar controls and user interactions and start to promote the platform as SAAS (software as a service) to reach a bigger market. Hopefully, we will find support to implement this technology as support for e-Learning at scale.

ACKNOWLEDGEMENTS: This work has been funded by the European Social Fund from the Sectoral Operational Program Human Capital 2014- 2020, through the Financial Agreement with the title "Scholarships for entrepreneurial education among doctoral students and postdoctoral researchers (Be Antreprenor!)", Contract no. 51680/09.07.2019 – SMIS code: 124539.

REFERENCES

- [1] Gicu Călin Deac, Crina Narcisa Georgescu, Cicerone Laurentiu Popa, Costel Emil Cotet. Virtual Reality Digital Twin for a Smart Factory. OPTIROB 2020, The 13-th edition of the International Conference Space Launching Systems and Artificial Intelligence in the fields of Aerospace, Robotics, Manufacturing Systems, Mechanical Engineering, Biomechanics, Power Energy, Materials Technology and Neurorehabilitation.
- [2] Boschert, S., & Rosen, R. (2016). Digital twin—the simulation aspect. In P. Hehenberger and D. Bradley. (Eds.) *Mechatronic futures: Challenges and Solutions for Mechatronic Systems and their Designers* (pp. 59–74). Cham: Springer.
- [3] Matsas E., & Vosniakos, G.-C. (2017). Design of a virtual reality training system for human–robot collaboration in manufacturing tasks. *International Journal on Interactive Design and Manufacturing (ijidem)*, 11, 139–153.
- [4] Abidi, M.-A., Lyonnet, B., Chevaillier, P., & Toscano, R. (2016) Contribution of virtual reality for lines production's simulation. *International Journal of Computer Theory and Engineering*, Vol. 8, No. 3, June 2016
- [5] Jerald, Jason, *VR Book: Human-Centered Design for Virtual Reality*, Association for Computing Machinery and Morgan & Claypool Publishers (2015), ISBN: 9781970001150
- [6] Dale, E. *Audio-Visual Methods in Teaching* (3rd ed.). The Dryden Press. (1969).