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Article

Metaverse in ports through an affinity diagram

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Abstract: A metaverse is an environment where humans interact socially and economically as avatars in cyberspace, which acts as a metaphor for the real world but without its physical or economic limitations. Many people use this new technology to connect with others, exchange content or discover new hobbies. Unlike other virtual worlds, the metaverse offers an online world that can be shaped. For the ports of the Spanish port system, it is intended to determine the new virtual port ecosystem that could be developed in the short term through an affinity diagram, which is a diagram that is used for the organization of ideas provided by a group on a complex problem that is held in a specific area, in this case reaching meta ports in the port system. The main conclusion is that to advance on this concept the new operating models and customers and services, are the blocks where the greatest efforts will have to be made.

Keywords: metaverse; ports; affinity diagram

1. Introduction

The Metaverse is a virtual world, one that you can connect to using a series of devices that will make you think that you are really inside it, interacting with all its elements. It will be like actually teleporting to a whole new world through virtual reality glasses and other complements that will allow us to interact with it (Mourtzis et al., 2022).

The metaverse is not intended to be a fantasy world, but a kind of alternative reality in which you can do the same things you do today outside your home, but without leaving your room (Allam et al., 2022).

The metaverse is a term that has recently gained popularity and generated a great deal of enthusiasm in the technology arena. In its most basic form, the metaverse refers to a shared virtual space in which people can interact with each other and with digital objects in real time. It is a virtual world in which multiple users can coexist and engage in a variety of activities, from working and learning to socializing and playing games. Unlike virtual reality and immersive experience, the metaverse is a persistent and constantly evolving digital representation of the real world, rather than an isolated experience (Gretzel and Koo, 2021).

Immersive experience encompasses a wide range of technologies and techniques that seek to create a sense of presence and full participation in an environment. Although virtual reality is a common form of immersive experience, it can also include other technologies, such as augmented reality (AR) and mixed reality (MR). Immersive experience seeks to integrate digital technology into the physical environment, overlaying virtual objects and elements on the real world or creating a fusion between the two (Hoyer et al., 2020).

Unlike VR, the immersive experience does not necessarily require a completely metaverse, but can enhance the existing reality by adding interactive digital layers (Mallam et al., 2019). Thus, the arrival of the Metaverse will positively impact many sectors of the economy, starting with the leisure and entertainment sector, as we already see in video games and sports; also in the education sector, which has great potential for growth in this new digital reality (González-Cancelas et al., 2023). Additionally, a significant growth in the use of the Metaverse by digital commerce is on the horizon, supported by the Blockchain and NFTs, which will differentiate it from Ecommerce as we know it (De Giovanni, 2023).

The metaverse is a broader concept and encompasses multiple interconnected metaverses, while virtual reality focuses on providing an immersive experience in a single environment (Allam et al., 2022). The metaverse is a constantly evolving virtual space in which users can interact and create experiences in real time. Artificial intelligence (AI) plays a fundamental role in the development and expansion of this digital universe, enabling the creation of more realistic and engaging worlds (Mhlanga, 2021).

The metaverse and logistics are two concepts that have a close relationship. Especially when viewed from the point of view of how logistics could play a role within the metaverse (Lin et al., 2022).

Indeed, in the context of the metaverse, logistics could play a role in managing the distribution of digital goods and services within that virtual space. For example, in a metaverse where people can buy and sell digital objects, a logistics infrastructure would be needed to manage transactions, store digital objects, and facilitate their delivery to buyers (Pooyandeh et al., 2022).

Phygital is an acronym for the words “physical” and “digital” and refers to the seamless integration of physical and digital experiences. It’s a concept that’s becoming increasingly important as businesses look for ways to create more engaging and personalized experiences for their customers (Maurya et al., 2022).

The concept of phygital can be applied to logistics in a number of ways. For example, businesses can use augmented reality (AR) to allow customers to see what products would look like in their homes before they buy them. They can also use virtual reality (VR) to allow customers to try on clothes or beauty products virtually. Companies can also use phygital technology to improve the efficiency of their logistics operations. For example, they can use artificial intelligence (AI) to automate tasks, such as inventory management or route planning (Batat, 2021).

In addition, another relevant fact about the metaverse and logistics is that the latter could be relevant in terms of the physical infrastructure needed to support the operation of the metaverse. This could include servers, data centers, network connections, and other logistical elements needed to ensure proper connectivity and performance of the metaverse (Qadir and Fatah, 2023).

While a fully immersive and interconnected metaverse is still years away, mobility stakeholders can already capture the real business value of the technologies designed to make it possible (Dwivedi et al., 2023).

Almost anything that can be done in the real world can be translated into the metaverse, as long as it fulfills its intended potential. However, new companies and organizations are appearing every day, inventing ways to be present in this fashionable virtual universe, making this idea more and more real (Templin et al., 2022).

Transportation companies also have their space within the metaverse, as they could basically offer the same services as in the real world (Buhalis et al., 2022).

So far, technology has made it possible to "democratize" and expand the possibilities of the supply chain around the world. With the advent of pandemic, process automation, the use of robotics, blockchain and other innovations have simplified operations (Dutta et al., 2020).

More importantly, their use has made companies truly put the user at the center of all efforts, as all of these processes are aimed at empowering and personalizing the consumer experience (Raza et al., 2023).

Research on the use of metaverses in ports globally is an emerging field, and research gaps can evolve rapidly. However, some potential research gaps in this area correspond to the following areas: Human-Metaverse Interaction in Port Operations, Security and Privacy in Metaports, Socioeconomic Impact, Integration with Existing Infrastructures, Adaptation to Technological Changes, Standardization and Regulations: and Stakeholder Engagement.

The most important questions that should be able to be solved with the course of this research should be, among others, how the introduction of metaverses affects human interaction in port operations, and what are the best practices to facilitate a smooth and efficient transition from traditional operational practices to metaverse environments. In addition, with respect to privacy and security, it should be possible to determine what the specific security and privacy challenges are. Regarding the long-term socio-economic impact of the introduction of metaports in port communities, it should be possible to determine how it will affect employees, businesses and local economies. Another concern is associated with the rapid technological changes associated with the implementation of metaports and the possibility of adapting port environments to achieve a successful transition. It will be of paramount importance not only to determine how the various stakeholders, such as governments, port authorities, businesses and civil society, can be effectively involved in the creation and management of metaports, but also what are the specific challenges in cross-sector collaboration in this context.

2. Review of literature

The metaverse is a term that refers to a shared virtual universe, simulated by a computer, in which users can interact and experience a virtual reality in real time. This experience can be achieved through virtual, augmented, or mixed reality and can include 3D representations of people, objects, and environments. The goal of the metaverse is to create a virtual world in which users can interact and experience an alternative reality to real life (Mozumder et al., 2022).

In the context of this research, the metaverse can be defined as a three-dimensional metaverse that simulates the physical space of a port and its operations. This environment allows the immersive interaction of users, to participate in activities related to the transport chain, port management, port operation and port operations. The ports metaverse includes elements of remote collaboration, real-time visualization, and the incorporation of emerging technologies.

As an example of this, we can think of a scenario where a port metaverse facilitates efficient management between different actors, such as suppliers, carriers and customs authorities, by allowing them to interact in a metaverse to coordinate and optimize the loading and unloading of goods. Worker avatars can access real-time data on container location, shipment status, and storage capacity, enabling faster and more accurate decision-making. The metaverse could even simulate complex situations, improving daily operations while contributing to greater resilience to unforeseen events, such as congestion at docks or unexpected changes in demand.

The metaverse has advanced significantly in several sectors, including video games, entertainment, education and training, business and commerce, and virtual reality. However, in recent years, the sector that has experienced the greatest advancement in the metaverse is video games and entertainment, thanks to the popularity of online games and the growing demand for immersive experiences. New applications are also being explored in other sectors, such as education and training, where metaverse solutions are being developed to improve the effectiveness and efficiency of teaching. In the future, we are likely to see further progress on the metaverse across a wide range of sectors (Kye et al., 2021).

The metaverse is one aspect of digitization. Digitalization refers to the process of transforming analog processes, information and products into digital format. The metaverse is a form of digitization in which a virtual universe is created that allows users to interact in a digital environment in real time (Bian et al., 2022).

In the metaverse, virtual reality and artificial intelligence combine to create an online experience in which users can participate in virtual activities, such as playing games, participating in conferences, doing business, etc. In this sense, the metaverse is considered an advanced form of digitalization that offers a more immersive and participatory virtual reality experience than other forms of virtual reality (Bibri et al., 2022).

The metaverse is a form of digitization that focuses on creating a real-time virtual experience that allows users to interact in a digital environment (Bisht et al., 2022).

The metaverse is also influencing the supply chain in various ways. This includes demand planning, where different demand scenarios are simulated and analyzed to enable companies to make informed decisions about production and supply chain planning (Kliestik et al., 2023). Additionally, it is utilized for supply chain simulation to assess its efficiency, identifying bottlenecks and solutions to enhance overall effectiveness (Jauhar et al., 2023). Real-time collaboration is another application, allowing companies to collaborate more efficiently with their supply chain partners, sharing information and making collective decisions (Perano et al., 2023). Furthermore, companies can leverage the metaverse to effectively showcase their products to customers, gaining valuable feedback and making informed decisions about production.

The metaverse is beginning to have an impact on the supply chain, offering new ways of planning, collaborating, and demonstrating products that improve supply chain efficiency and effectiveness (Perano et al., 2023; Romagnoli et al., 2023).

The supply chain in the digital age has become a broad concept based on systems, analytics and tracking of goods, vehicles and other assets through what we know as IoT (Internet of Things), bringing significant improvements in the operation of supply chains (Rejeb et al., 2019).

Technologies such as predictive analytics, a statistical technique that analyzes actual historical and current data to make predictions about unknown or future events, improve visibility into the movement of goods, and robotics help DCS (Distributed Control System) keep pace with supply chain management in the digital age (Lv et al., 2022).

Technological trends in the supply chain encompass various developments. Notably, there is a growing emphasis on network-centric visibility (Ng and Cruickshank, 2023) to enhance transparency. Integrating the Internet of Things (IoT) with application processes is becoming pivotal for streamlined operations (Ahmad et al., 2023). Scenario-based planning (Dincelli and Yayla, 2022) is emerging as a strategic approach, while the implementation of IoT, smart routing, and predictive analytics is shaping the future of supply chain dynamics (Neethirajan, 2023). Mobile robotics is inducing transformative changes in Distributed Control Systems (DCS) (Biswas et al., 2023), and the anticipation of Cloud Transportation Management Systems (Cloud TMS) breaking down information silos signals a paradigm shift in information management (Yao et al., 2022).

Many application categories are adopting Cloud TMS implementation as a natural solution because it transforms transportation management from an internal activity into a process that can easily connect with third-party logistics providers (Mozumder et al., 2023).

Some of the risks involved in the metaverse:

- Hacking headphones and microphones (Qamar et al., 2023).
- Biometric data theft (Gadekallu et al., 2023) (Wu and Zhang, 2023).
- Behavioral data (Allam et al., 2022).
- Compromised Privacy (Dwivedi et al., 2023).

The metaverse is a project under permanent construction. Just as the Internet has been in the last decades (Sopher and Lescop, 2023).

Maritime traffic does not want to be oblivious to the potential of the metaverse. In the maritime environment, the advantages and applications of the metaverse are being exploited, especially in improving efficiency and for the collaboration of the supply chain, of which ports are just another link. Some of the uses of the Metaverse applied to maritime traffic would be:

- The metaverse enables the creation of customized virtual port environments, allowing the simulation of specific situations and the practice of specific skills. This allows for more customized simulation and training tailored to the needs of the ports (González-Cancelas et al., 2023).
- As a tool for collaborative work, the metaverse can accomplish much more than simply bringing teams together in a unified space. The metaverse promises to bring new levels of connectivity to the virtual work world, allowing people working in the supply and transportation chain associated with ports to interact in real time with digital twins, explore different environments securely, and share information like never before (Allam et al., 2022).
- Regarding maritime traffic. The metaverse will offer simulations with different operations and scenarios, to test them before opting for one or the other. This type of hypothetical simulations is called virtual twins (Mourtzis et al., 2022).

- With data and analysis in the metaverse, different shipping route schedules could be simulated and their efficiency evaluated. This could help port professionals to optimize shipping routes. In addition, it will also be possible to reduce transportation costs, minimize delivery times and improve the sustainability of logistics operations (Huynh-The et al., 2023).

Improving efficiency in ports is an element of constant study and improvement, with the help of the metaverse real time information about maritime traffic and activity in the port can be visualized, furthermore the simulation of different scenarios allows planning and managing port capacity by modeling port capacity, optimizing port capacity and improving efficiency in terms of time and cost (González-Cancelas et al., 2023).

The metaverse has numerous artificial intelligence and machine learning tools that can be employed to improve port planning and capacity, although no specific tools exist to date, simulation platforms can be used to test different scenarios and assess their impact on capacity (Allam et al., 2022).

With the metaverse, real-time data can be employed that allows companies to manage and process large volumes of data in motion, therefore it can be employed by the port environment to find real-time solutions, as it allows real-time data flow between applications and systems (Deveci et al., 2022).

Data in Motion refers to data that is generated in real time and constantly moving between systems, applications and devices. This data in motion includes everything from financial transactions and sensor data to social media messages and server logs, allowing for real-time solutions, identifying problems in real time and attempting to respond to them almost automatically and improving efficiency (Zhang et al., 2022).

In the port environment, the metaverse can be primarily fueled by various technological tools. Project management software acts as a connector, facilitating collaboration among teams and enabling all organization members to prioritize crucial tasks (Deveci et al., 2022). Virtual reality platforms, defined as environments where technology generates realistic images and simulates presence, offer new possibilities for interaction and visualization (González-Cancelas et al., 2023). Management information systems extract internal system data and summarize it into useful formats, such as management reports, supporting activities and decision-making, allowing port stakeholders to share and collaborate on documents in real-time (Damar, 2021). Communication tools, enabling the transmission and reception of messages, play a crucial role in connecting and effectively coordinating participants within the port metaverse (Tang et al., 2022).

The metaverse in the port environment can be powered mainly by the following tools:

There are several tools that can be used to enhance real-time collaboration in ports aided by the metaverse (Yoon and Oh, 2022) (**Figure 1**).

These tools can help improve efficiency and productivity in port collaboration aided by the metaverse (Duan et al., 2021).

The metaverse is considered the next evolution of the Internet, it could be expressed as a 3D Internet, persistent three-dimensional spaces that integrate the virtual and real world. A different way of interacting with users and companies through avatars, the equivalent of a user profile in a social network. No one now doubts the benefits and importance of social networks for companies, so it is difficult to doubt their natural evolution (González-Cancelas et al., 2023).

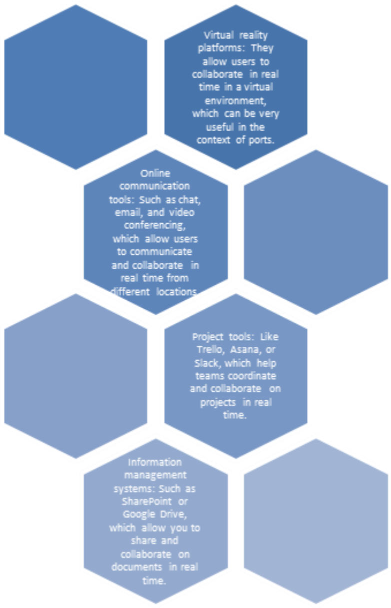

Figure 1. Tools for enhance real-time collaboration. Source: own source.

Based on the fact that the metaverse functions as a virtual complement to the real world, it can be understood that digital twins can be part of the metaverse (Singh et al., 2022). For example, the information of the transport in which we travel (car, plane, boat ...) acquired through the sensors feeds its digital twin with real-time data and at the same time it allows us to publish the information we want to share, such as geolocation, weather conditions, camera view in our favorite social network within the metaverse, associated with our representative who is the avatar (De Giovanni, 2023).

3D models can help the visualization of information in ports, the metaverse collaborates to increase our value chain, increases competitiveness, the differentiation of our products and their perception of quality (González-Cancelas et al., 2023).

Virtual reality, artificial intelligence, interactivity, blockchain, IoT, digital twin... the metaverse of logistics, the next revolution born from the internet, poses new challenges for the port environment. Born in the gamer environment, the metaverse has spread to all facets of social and business life, redefining the scenario of the physical and the virtual, where both represent two sides of the same coin (Mourtzis et al., 2022).

The metaverse is a broad concept that can exist without the need for AI. In fact, there are some metaverses that don’t use AI at all.

However, AI has the potential to significantly improve the metaverse experience. For example, AI can be used to generate user-generated content (UGC), create realistic virtual characters, and provide more personalized user experiences.

Consequently, while AI is not central to the existence of a metaverse, it is a technology that has the potential to transform the way we interact with these virtual worlds.

Port activity has been entering the virtual world for some time now, although so far not with avatars but with simulation programs for augmented reality. The metaverse is more than just an online representation, and the key lies in the digitalization of port profiles and processes linked to port operations, as well as in the interoperability of future scenarios (Secchi and Gili, 2022).

For port operators, it represents a further step in the digitization of the sector, including a multisensory factor perceived by the user through the use of peripheral devices. Thus, the combination of technologies that have already been used separately (blockchain, virtual reality, artificial intelligence or IoT) and the application of 5G achieve the immersion of the user in port operations (González-Cancelas et al., 2023).

The implementation of metaports in port environments faces significant challenges that require detailed attention. One of the key challenges lies in adapting traditional port infrastructures to the technological and virtual requirements of metaports. Interoperability between existing systems and new technologies presents obstacles, as well as the effective integration of real-time data from multiple sources, as outlined in (de la Peña Zarzuelo et al., 2020).

Recent research highlights that another critical challenge is acceptance and adoption by port stakeholders. The introduction of metaports implies a significant cultural and operational change, which could generate resistance and require effective organizational change strategies, it is appreciated that the necessary cultural change is not permeating organizations (Allam et al., 2022).

When talking about anymetaverse, security and privacy are constant concerns. Protecting sensitive data and managing cybersecurity are critical challenges that need to be addressed to ensure user trust and the integrity of port operations in the metaverse (Wylde et al., 2023).

These challenges are crucial because they directly affect the efficiency and feasibility of implementing metaports in the port system. The research focuses on addressing these challenges proactively, proposing practical solutions and innovative strategies. Through a comprehensive approach, it seeks not only to overcome technical and operational barriers, but also to promote a smooth and successful transition to virtual port environments, thus maximizing the potential benefits for all parties involved and that the metaverse can become a reality in Spanish ports

3. Materials and methods

The following diagram (**Figure 2**) shows the different phases of the methodology to be used:

An affinity diagram, also known as an affinity map, is a visual tool used to organize information (**Figure 3**). By classifying data or ideas by common themes, a team can develop new ways to process complex problems (González-Cancelas et al., 2022).

A diagram is a graphic in which information about a process or system is simplified and schematized. It can be simple or complex, with few or many elements. It is a complete summary, which serves to know and interpret information in a simple and visual way (González-Cancelas et al., 2022).

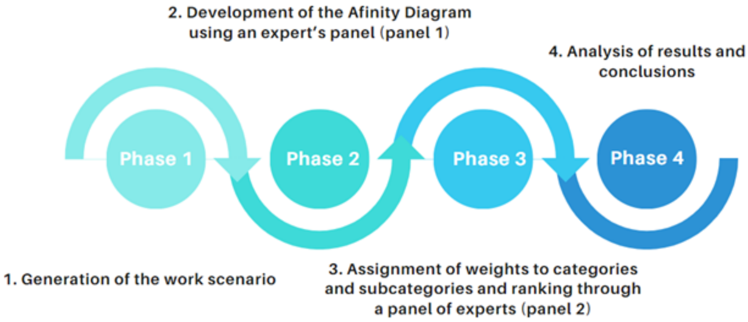

Figure 2. Methodology scheme. Source: own source.

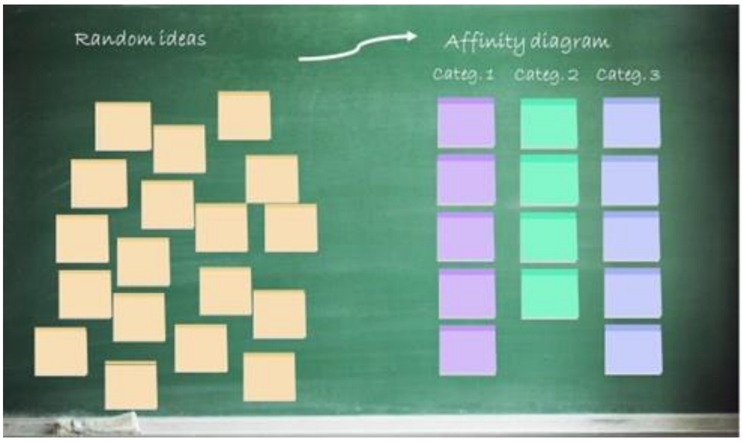

Figure 3. How the affinity diagram works. Source: own source.

The main advantages of using the affinity diagram are (González-Cancelas et al., 2022):

- Organizes many ideas and concepts, very useful when you have a large volume of information without order.
- Allows you to understand a situation or problem in more depth.
- It manages to focus the efforts of the work group, which allows you to work as a team.
- It is a visual method, which induces group creativity.
- Facilitates subsequent analysis.
- It is used in many fields, and being one of the 7 new quality tools, of course you can use it in quality control issues.

The method is mainly used when information needs to be sorted and grouped; but what if there is not so much information that needs to be sorted. It is advisable to use it when there are more than 12 elements, otherwise analyzing the ideas separately is more than enough (Fowlkes et al., 2004).

The steps to be developed are the following (**Figure 4**) (González-Cancelas et al., 2022).

The selection of experts in the field of application for the generation of the affinity diagram is based on the need to cover a diversity of perspectives and experiences, thus ensuring a comprehensive representation of knowledge in the area. This extensive group of experts seeks to reduce individual biases, validate findings, and deepen the exploration of ideas, enriching the diagram with a variety of voices and insights. Meaningful expert involvement not only enhances the credibility of the study, but also makes it easier to identify key relationships and gain consensus around the importance of relevant factors in the field of application.

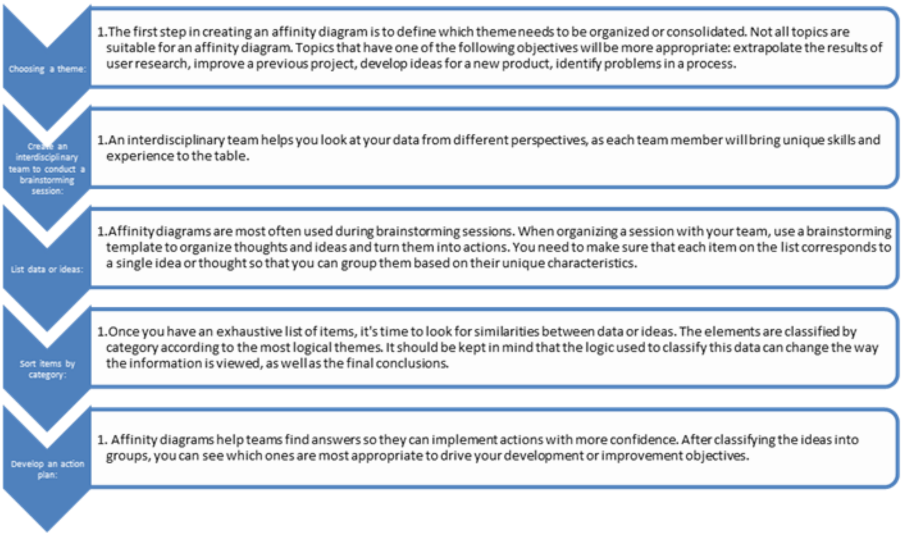

Figure 4. Steps of affinity diagram. Source: own source.

In the selection of experts for the generation of the affinity diagram, rigorous criteria were applied based on professional experience, thematic specialization, diverse representation, previous achievements and contributions, collaborative skills, interdisciplinarity, availability and commitment, as well as recognition in the scientific community. These criteria ensure an equitable and meaningful participation of experts with diverse perspectives and expertise in the field, thereby strengthening the validity and breadth of the analysis in the study.

The dynamic of conducting two different expert panels in the research study has been an effective strategy to address different aspects of the research and enrich the quality of your results. The dynamics and justification for choosing two different panels are explained below, as well as the advantages of having carried out these dynamics:

Dynamics of the Expert Panels:

Panel 1: Affinity Diagram in Metaverse in Spanish Ports (Participants from the Academic World, 15 People):

- Selection of Experts: A group of experts was chosen, mainly from the academic field, which ensured a solid and theoretical knowledge base on the subject of the metaverse in Spanish ports.
- Brainstorming strategy: Experts participated in brainstorming sessions to generate a wide range of ideas and concepts related to the metaverse and its application in ports.
- Creation of the Affinity Diagram: From the ideas generated, an affinity diagram was created that helped organize and structure the ideas and concepts.

Panel 2: Weighting of Blocks and Subblocks (Participants from the World of Consulting, Port Actors and Academics, 10 Experts):

- Selection of Diversified Experts: A diverse group of experts was chosen, including consulting professionals, port actors, and academics. This diversity ensured a variety of perspectives and experiences.

- Evaluation of Blocks and Subblocks: Experts evaluated and assigned weights to the blocks and subblocks of the affinity diagram created in Panel 1. This assessment was based on the relevance and priority of each block and sub-block in relation to the metaverse in Spanish ports.
- Reaching Consensus: Experts participated in online discussions and negotiations until reaching consensus elements in the allocation of weights.

4. Results

The working group was formed by 22 people related to the Spanish port area, a leader and two coordinators were appointed. The working session took place over the course of a morning in which the members of the team met in person.

An element to take into account when designing an affinity diagram is that the working group must be made up of trained personnel in the subject on which it is discussed, because only in this way is it guaranteed that the conclusions drawn from the process are really useful and accurate. That is why the creation and selection of the group of experts was much discussed.

The experts knowledgeable about the subject of work included in post-it the key elmentos to have the account for the metaports and later with the help of the leaders and coordinators these indicators were exposed and by consensus they were grouped into different groups.

4.1. Category 1: Data

Data collection: DR

RD1: Real-time data. Obtaining data (entry/exit of goods/ships...) in real time between the sections of the port, the status of the goods and the rest of the country's ports. Getting and storing data is the first step in turning a port into a "metaport."

RD2: Exchange of information in the transport chain. A fundamental aspect for the development of a port is its connectivity and accessibility from the land side from the point of view of the exchange of information in the transport chain: it is essential that port infrastructure is integrated with land transport through effective systems and means.

RD3: Open-data. The creation of an open and updated database, searchable by universities and companies in the sector and local, which serves as a meeting point for the public and private sector forming alliances that allow the development of applications and innovative ideas for the digitalization of the port.

RD4: Cloud computing. For the correct and effective functioning of all the operations that take place in a port it is necessary to know, manage and be able to analyze the data quickly and safely.

4.2. Category 2: New operating models

4.2.1. Interface: IN

IN1: Loading-unloading systems modernization. Modernization of ship unloading systems to obtain a combination of technology and human labor, just as on Indonesian farms where stevedores can remotely perform their work.

IN2: Port status monitoring: Real-time port conditions. Through images, cameras or some kind of sensor it is possible to constantly monitor the status of a port in all its aspects. This allows faster intervention in case of breakdown or malfunction.

IN3: Autonomous vehicles by remote control. Self-driving vehicles use artificial intelligence to function. In a "metaport" they are necessary to integrate the digitized system to the vehicles that transport goods within the port and the different areas.

IN4: Digital planning and management instruments. Ports must use digital instruments for planning and management, and integrate all data inside. With the idea of digitizing all the information and reaching a "metaport", it is important to start using new technologies and integrate the port data for later use.

IN5: Programmed comodality. Both the shipping company and the sender or receiver of the cargo will have an identified access in a virtual platform of the port itself, which allows them to calculate and contract the optimal transport chain.

IN6: Metaformation. Creation of a model of the port in the metaverse in which professionals can practice tasks such as towing ships on arrival and departure from port, loading and unloading by cranes carried out by stevedores or even tasks such as the detection of prohibited goods (drugs, weapons, etc.) and situations of terrorism for the security forces of the port.

IN7: Traceability of goods (GIS). It consists of, through geographic information systems, tracking goods or ro-ro cargo in terminals.

IN8: Real-time docking/undocking. Develop real-time ship monitoring systems that allow knowing their situation both to estimate the hours of arrival at port, and to estimate the time of departure once the loading and unloading or embarkation and disembarkation operations have been completed. This would improve operations and quality of service.

4.2.2. Automation: AU

AU1: Identification of vessels through smart technology. Detection and identification of ships by serial numbers/codes through intelligent technology for better management and organization prior to arrival at port.

AU2: Artificial intelligence software. They need to practice and develop software to reach a very effective artificial intelligence A "metaport" works with artificial intelligence.

AU3: Blockchain system. The use of blockchain technology is indispensable for a port that aims to be fully digitized.

AU4: Robotization. Implementation of autonomous robots in different processes of the supply chain.

AU5: Self-guided equipment. Implementation of self-guided equipment, such as drones, that help the physical security of the port through its continuous processing of information through real-time inspection of the port and send this information to security systems and equipment.

AU6: Simulation. Development of simulation systems within the supply chain.

4.2.3. Cybersecurity: CB

CB1: Data security. All digitized data must be secure, there will be data that can be public, such as the occupation of the port in real time, and others that only the client can know, such as the status of their cargo, how and when it will be transported etc.

CB2: Physical infrastructure at the service of data collection. Technologically advanced cameras must constantly monitor all places in the port and keep track of the recordings made, allowing total remote control through apps or software.

CB3: Security protocol management. Ensure the implementation of effective security protocols that address cyber threats and ensure the protection of critical data and systems in ports.

CB4: Security training and awareness. Train port staff in cybersecurity practices and threat awareness. Ensure that all actors in the port are well-informed and prepared to address potential vulnerabilities and security risks.

CB5: Cyber incident management. Develop an incident response plan to identify, contain and mitigate cyber incidents in the port environment. This includes the formation of response teams and the documentation of procedures.

CB6: Technical support and quick resolution. Establish an efficient technical support system to address technical problems and ensure a quick resolution of incidents that may arise in the daily operations of the port. This involves the availability of trained personnel and incident tracking systems.

4.3. Category 3: Customers and services

4.3.1. Customer relationship: CR

CR1: Information connections "post-port". Implement the system of collection and exploitation of the transport data "post-port" of the different goods that arrive at the port in a real way, including any unforeseen event or change that must be included in these data.

CR2: Meetings in virtual reality. Through the use of virtual reality viewers, create virtual meetings that simulate the physical presence of those present in the same room or in the same collaborative environment, achieving a correct interaction between the subjects.

CR3: Process simulators in virtual reality. Simulate, test and teach the client activities without having to do them. Through the use of virtual and augmented reality, it is possible to simulate and let customers try activities so that they can buy them having had the best possible prediction of reality.

CR4: Decision support. Provide services and tools that help port customers make informed and strategic decisions. This involves offering advice, data analytics, and resources that enable customers to optimize their operations and transportation routes efficiently and cost-effectively.

4.3.2. Quality of service: SC

SC1: Data interconnection. Improvement of the internal data connections of the port, everything must be interconnected with the data processed and shared with the personnel / client that concerns you.

SC2: Need to compare with other ports to remain competitive. In order for port planning to be more efficient and more in line with the latest technological and technical developments, the port management mode must be compared with others, in order to remain competitive.

SC3: Propose new challenges in the supply chain. The supply chain of a port faces many challenges, such as cost control, customer service, supplier management... To become a "metaport", new challenges are needed to improve and remain competitive.

SC4: Interactivity and interoperability. To become a digitized and modern port, it is essential that data exchange is fast and efficient.

SC5: Cost reduction and increased productivity. By replacing older machinery and technologies with more modern, technologically advanced, efficient and sustainable ones, it is possible to reduce costs and time throughout the port system and, at the same time, increase productivity.

SC6: Virtual reality training courses. Training courses within virtual reality allow more people to participate, increasing the level of overall training of employees. They also significantly improve the experience and create a more favorable learning climate.

SC7: Pollution reduction and sustainable solutions. Pollution is an important issue today and will be even more so tomorrow. The data used by new technologies should help us reduce our pollution and find more sustainable solutions to the "metaport".

SC8: Optimization of sectors involved. In a port there are different sectors. The demands of each sector that develops the port are different. It is essential to have a personalized approach for each sector and, therefore, customize its management in the metaverse.

SC9: Operational efficiency assessment. Implement an operational efficiency measurement system that allows the evaluation and optimization of processes in the port.

4.3.3. Port management: PM

PM1: Monitoring of all processes. Monitoring of all the processes carried out by the port, in order to find those processes with less efficiency or that are a bottleneck within other more complex processes, either to make small adjustments to the process, or to increase the number of process workers or to find new ways to carry out that process.

PM2: Energy management. Monitoring electricity, fuel, water and gas supply activities would optimize the consumption of these resources. Through this monitoring, processes could be integrated and automated to reduce costs.

PM3: Waste management. The volume of waste from ships could be quantified through sensors that model the solid generated. With this system, it would be possible to dispense with the agents in charge of reviewing the production of this waste, and reduce the costs derived from these inspections.

PM4: Virtual customs inspections. Virtual customs inspections at any port. In this way, customs inspectors would not have to go in person to inspect the merchandise, but could do so virtually in the metaverse.

PM5: Innovation and technological development. Promote innovation and technological development in the port to improve efficiency and competitiveness.

PM6: Circular economy management. Promote circular economy practices in the port, reducing waste and promoting the reuse and recycling of resources.

PM7: Optimization of port operations. Constantly seek to optimize the port's operations, from the reception of goods to loading onto ships.

4.4. Category 4: Cooperation and institutional coordination: CC

CC1: Incubators and start-ups. Creation of an incubator for the development of integrated solutions with the port authority, the maritime industry could make funds available to finance start-ups whose vocation is to provide them with new digital tools.

CC2: Internal entities of metaverse deployment. In many companies in these sectors, internal entities have been created to deploy digitalization.

CC3: Public-private collaboration and involvement. Encourage collaboration and active involvement of both the public and private sectors in the implementation of port improvements.

CC4: Public institutions with control and supervisory functions. The State and the different municipalities must have a kind of control and supervision function.

CC5: "Goal" spaces. More office spaces are needed so that the "goal" part can be developed. For this it is necessary that Internet connections work, as well as 5G.

CC6: Decision making support. Provide resources and advice to assist stakeholders in making strategic decisions related to port modernization.

4.5. Category 5: Technological maturity and sectoral assimilation

TM1: Technological maturity. It comprises the degree of adoption of metaverse technologies in the port sector and the existence of metaverse-related product standards.

TM2: Assimilation capacity of the sector. It should take into account the level of education and skilling of port staff in metaverse technologies, as well as the degree of acceptance and participation of port companies in metaverse projects.

TM3: Technological homogenization. On this point, the degree of compatibility between the different technological tools used by Spanish ports will be fundamental, as well as the level of interoperability between systems and platforms related to the metaverse.

TM4: Diversity of port tools. As is the case in the Spanish port sector, it will be necessary to determine the number of specific tools used by different ports, in order to establish the degree of complexity in the management of multiple technological systems in the same port, so that an evaluation of the efficiency and effectiveness of the existing tools can be carried out.

TM5: Acceptance and fear of change. It would be necessary to know in advance the willingness of the actors in the port sector to adopt metaverse technologies, as well as to identify the barriers and concerns related to the assimilation of these technologies, for this communication and awareness strategies in the sector must be evaluated.

In the **Figure 5** it can be seen the affinity diagram. With the second panel of experts, the following elements were obtained (**Figure 6**). The dynamic of using two different expert panels in the research study was an effective strategy to address different aspects of the topic, enrich the content, and ensure validation of the results through expert consensus.

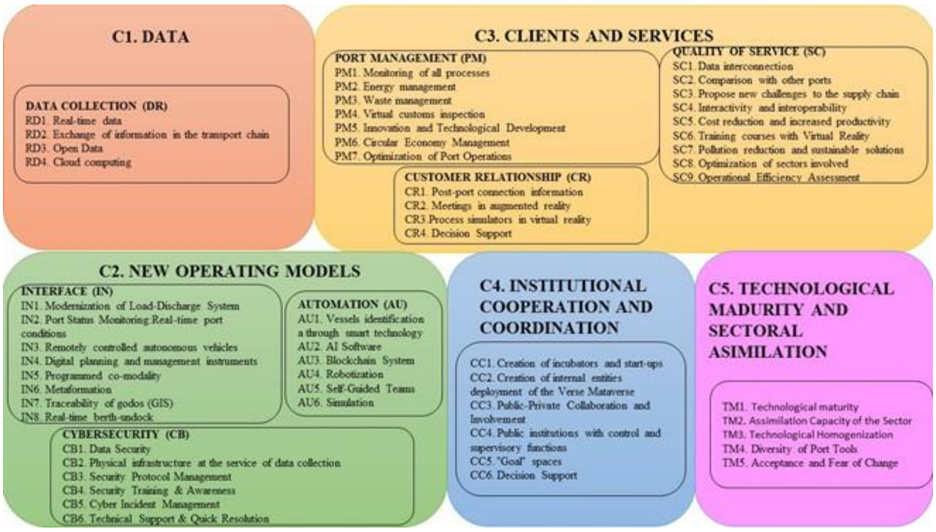

Figure 5. Affinity diagram. Source: own source.

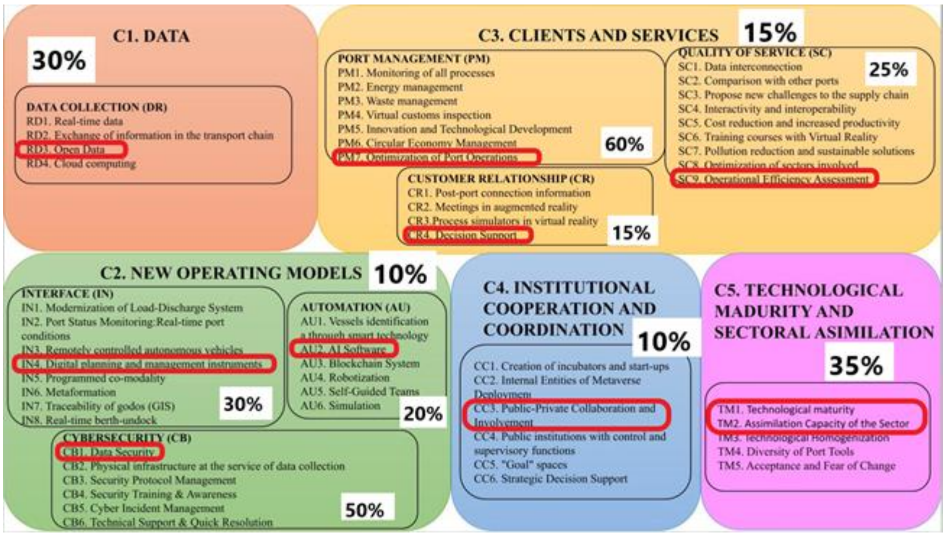

Figure 6. Weights in the affinity diagram. Source: own source.

5. Analysis of results

This study focuses on the evaluation of the implementation of the metaverse in the port context, highlighting two main categories that have proven to be of great relevance in this analysis: Category 1 (Data) and Category 5 (Technological Maturity and Sector Assimilation).

Category 1, which accounts for 30% of the weight in our research, focuses on the importance of data collection and management in ports. The research has revealed that obtaining real-time data, interoperability of information systems in the transport chain, and the creation of open databases are essential pillars in the transformation of ports into true 'metaports'. These findings underscore the need to establish efficient data collection and management systems to drive digitalization and automation in the port sector.

On the other hand, Category 5, which accounts for 35% in this analysis, focuses on the technological maturity and assimilation capacity of the port sector in relation to the metaverse. The study has identified the importance of staff training, the acceptance of port companies in metaverse projects, technological homogenization and the evaluation of the diversity of tools used. In addition, it is crucial to understand the willingness of industry players to adopt these technologies and address the barriers and concerns related to their uptake. These results emphasize the need to develop specific strategies to foster the adoption of the metaverse in the port sector.

Taken together, the research findings underscore the importance of Category C1 in the fundamental foundation of transforming ports into 'metaports' through data management, while Category 5 plays a crucial role in assessing the sector's technological maturity and ability to successfully adopt and integrate metaverse technologies. These findings are essential to inform future implementation and development strategies in the port space in the metaverse era.

If Category 2 (New operating models) has a weight of 10% in the analysis of your study for the transformation of Spanish ports into "metaports," this means that in the context of the study, the considerations related to the new operating models contribute 10% to the overall assessment of the feasibility and effectiveness of this transformation.

This focus on institutional cooperation and coordination underscores the importance of involving multiple actors and stakeholders in the transformation process. Although this category has a weight of 10%, its impact on collaboration and ensuring that the interests of both the public and private sectors are considered on the path to digitalisation and the creation of 'metaports' cannot be underestimated. It is essential to remember that, although each category has its own weight in the analysis, the synergy between all categories is essential for an effective and complete transformation of Spanish ports towards the desired future of 'metaports'."

According to the results of the panel of experts, the emphasis and priority in the transformation of ports into "metaports" lies in the creation of an open and updated database, accessible to universities and companies in the sector. This has several implications for the analysis of results:

Emphasis on Open Data: The analysis should highlight that the panel of experts prioritizes open data in the transformation process. This suggests that they consider it critical for ports to provide open data that is accessible to various actors, which can foster innovation and collaboration in the sector.

Collaboration and Partnerships: The emphasis in RD3 indicates the importance of fostering collaboration between universities, companies and other stakeholders in the port area. This may involve the formation of alliances for the development of innovative applications and solutions in the context of port digitalisation.

Data Unification and Automation: Creating an open and up-to-date database is key to data unification and automation in ports. This can lead to greater efficiency and consistency in information management across ports, which is essential on the road to "metaports".

Communication of Results: In the analysis of results, it should be highlighted how the priority given to RD3 influences the strategies and approaches recommended for port transformation. It is important to communicate how this emphasis on open data can contribute to the digitization and modernization of ports and the achievement of "metaport" goals.

According to the expert panel, the most driving elements in Category 2 (New operating models) are IN4 (Digital planning and management instruments), AU2 (Artificial Intelligence Software) and CB1 (Data Security), each within its subcategory, this means that these elements play a prominent role in the transformation of ports into "metaports" from the perspectives of digital planning and management, Artificial intelligence and data security.

The IN4 element, which focuses on the adoption of digital tools for the planning and management of port operations, represents a cornerstone in the transformation towards "metaports." The digitalization of planning and management processes is essential to improve efficiency and coordination in ports. By adopting digital technologies and tools, Spanish ports can optimize resource management, schedule operations, and improve decision-making. Digital planning and management allow for greater synchronization of operations, which is crucial for operational efficiency and cost reduction.

AU2 highlights the importance of developing artificial intelligence software to drive port transformation. Artificial intelligence plays a critical role in automating and optimizing port operations. Implementing AI algorithms can improve efficiency in resource allocation, demand forecasting, and decision-making based on real-time data. In addition, AI can contribute to the early detection of problems and the continuous improvement of port processes. This is essential for the transformation of ports into highly efficient and technologically advanced "metaports".

CB1, which focuses on data security, is a critical component of the transformation to "metaports." In a digitalized environment, the protection of sensitive data is essential. Ensuring the confidentiality, integrity, and availability of data is critical to the safe operation of ports. Implementing effective security measures, such as encryption, authentication, and constant monitoring, is crucial to prevent security breaches and protect critical information. Data security is a pillar for customer trust and the long-term sustainability of "metaports".

These driving elements in Category 2 indicate that digitalization, artificial intelligence and data security are critical to driving the transformation of Spanish ports into highly efficient, technologically advanced and secure "metaports". The combination of advanced technology and robust security measures will enable ports to adapt to changing demands and achieve greater efficiency in their operations.

For category 3, according to the panel of experts, the identification of the most important elements to boost Spanish "metaports" in the short term such as PM7 (Optimization of Port Operations), CR4 (Decision Making Support) and SC9 (Evaluation of Operational Efficiency) has important implications for the future of Spanish ports. Below, we'll take a look at what this means for Spanish ports.

The priority given to the optimisation of port operations (PM7) points to the importance of improving efficiency at all stages of port operations, from the reception of goods to loading onto ships. For Spanish ports, this implies:

Increased Efficiency: Optimizing processes and implementing advanced supply chain management systems will enable greater efficiency in port operations. This will result in reduced costs, increased productivity, and faster turnaround times.

Competitiveness: Spanish "metaports" will be more competitive internationally by offering more efficient and profitable operations. This will attract more businesses and cargo, which will boost economic growth.

Advanced Technology: The adoption of advanced technologies, such as automation, real-time tracking and artificial intelligence, will play a fundamental role in optimizing port operations.

The importance of supporting port customers in decision-making (CR4) involves a focus on collaboration and the provision of services that help customers optimize their operations. This means:

Client-Port Relationship: Spanish "metaports" will be more focused on building strong relationships with their customers. This will include advice, data analysis, and resources that enable clients to make informed, strategic decisions.

Supply Chain Efficiency: Ports will become strategic partners for their customers, providing services that enable more efficient supply chain management. Informed decision-making will improve customers' competitiveness.

Customized Services: Spanish ports will offer customized services and tailor-made solutions to meet the specific needs of customers. This will foster customer loyalty and business growth.

The implementation of an operational efficiency measurement system (SC9) highlights the importance of constantly evaluating and optimizing processes in the port. This involves:

Continuous Improvement: Spanish "metaports" will be committed to a culture of continuous improvement. Constant evaluation will allow you to identify areas for improvement and take corrective action.

Operational Efficiency: Operational efficiency is essential to better serve customers. Measuring and optimizing efficiency will ensure that operations are conducted as efficiently as possible.

Customer Experience: Evaluating operational efficiency not only benefits the port but also customers. More efficient operations improve the customer experience and strengthen business relationships.

The prioritisation of PM7, CR4 and SC9 means that Spanish "metaports" will focus on process optimisation, efficiency improvement, informed decision-making, collaboration with customers and constant evaluation of operations. This will contribute to a more competitive, technologically advanced and customer-oriented port, driving growth and excellence in the Spanish port sector.

The identification of CC3 (Public-Private Collaboration and Involvement) as the most important element to promote the transformation of Spanish ports into "metaports" within Category 4 (Cooperation and institutional coordination) has a solid and significant justification, CC3 (Public-Private Collaboration and Involvement) is fundamental for the promotion of Spanish ports towards "metaports" due to its capacity to foster strategic collaboration, shared finance, innovation and sustainable development. Public-private collaboration makes it possible to face the challenges and take advantage of the opportunities in port modernization, promoting faster and more sustainable growth in the Spanish port sector.

The identification of both TM1 (Technological Maturity) and TM2 (Sector Assimilation Capacity) as drivers to turn Spanish ports into "metaports" is of great relevance. This is because these elements play a critical role in modernizing ports and adapting them to a digital and metaverse environment.

TM1 (Technology Maturity) points out the importance of being at the forefront of the adoption of digital and metaverse technologies. This implies that Spanish ports must embrace advanced technologies, such as virtual reality, artificial intelligence, and automation, to improve their efficiency, safety, and sustainability. In addition, the existence of standards and protocols in the sector is essential to ensure interoperability and system integration. Investing in research and development of metaverse technologies is a crucial element of staying competitive in an ever-evolving environment.

TM2 (Sector Assimilation Capacity) highlights the need for port staff to be trained and prepared to adopt and leverage these technologies effectively. Education and training are essential to ensure that staff can adapt to new technologies. Collaboration with other industries, such as aeronautics, can provide valuable knowledge and experience in adopting digital technologies. In addition, the existence of policies and programs to encourage the adoption of the metaverse in the sector is a crucial factor in driving technological modernization.

The combination of Technological Maturity (TM1) and Sector Assimilation Capacity (TM2) indicates that Spanish ports are committed to the adoption of advanced technologies and the training of their staff to assimilate these technologies effectively. This strategy is essential to deliver more efficient, safe, and sustainable operations, improve competitiveness, and provide high-quality service to its customers. The successful transformation of ports into "metaports" depends to a large extent on the combination of technological maturity and assimilation capacity of the sector.

For the case study: Determining the percentage of progress of Port1 towards "metaport" status would require a detailed and specific assessment based on several factors, including the implementation of technologies, training of personnel, collaboration with other industries, and the adoption of sustainable practices.

An overall assessment can be provided based on the information obtained:

Category 1: Data (3/10 of 30%): The Port of Algeciras has made significant progress in the collection, management and use of real-time data (RD1), exchange of information in the transport chain (RD2), creation of an open database (RD3) and the implementation of cloud technologies (RD4), could have a significant percentage in this category.

Category 2: New Operating Models (3.5/10 of 10%): Port1 would have to demonstrate a high degree of modernization in loading and unloading systems (IN1), real-time control of port conditions (IN2), adoption of autonomous vehicles (IN3), use of digital tools for planning and management (IN4), as well as the implementation of scheduled modalities (IN5). The adoption of these advanced operating models would contribute significantly to this percentage.

Category 3: Customers and Services (?): For this category, the implementation of virtual reality technologies, such as virtual meetings (CR2), virtual reality simulators (CR3), and decision support (CR4) would be required to meet customer needs and improve service quality. In addition, improving quality of service (SC1) and data interconnection (SC2) are also critical factors.

Category 4: Cooperation and Institutional Coordination (8/10 of 15%): Cooperation and collaboration with other actors in the sector and the creation of incubators and startups (CC1) are essential. Port1 must demonstrate its ability to promote these initiatives.

Category 5: Technological Maturity and Sectoral Assimilation (2.5/10 of /35%): Technological maturity (TM1) and industry assimilation capacity (TM2) are critical. The port must be at the forefront of adopting metaverse technologies and be able to assimilate these technologies effectively.

Transformation to a "metaport" is an ongoing process that can take significant time and resources to fully achieve.

6. Conclusion

Virtual reality, artificial intelligence, interactivity, blockchain, IoT, digital twin... The metaverse of logistics, the next revolution born of the internet, poses new challenges for supply chains and of course for the future of ports The metaverse is a leap in internet connectivity, supported by 5G and characterized by interactivity, simulation, a decentralized environment and a reality that, although virtual, it persists and is directly linked to the real one. The metaverse is a step further, since it is not only able to faithfully reproduce what happens in a certain space, but also recreates a parallel universe with which we can interact. In this parallel reality we can propose or simulate alternative scenarios for different purposes.

The blocks with the highest number of indicators correspond to new operating models and to customers and services, it is in these blocks where the greatest efforts will have to be made.

Within the operating models is automation, the metaverse could allow the implementation of autonomous systems for the transport and loading of goods, as well as for the maintenance and repair of port equipment. These systems could be remotely controlled and monitored in real time across the metaverse, reducing the need for human intervention and minimizing the risks associated with workplace accidents.

Regarding cybersecurity, security is a critical aspect in the operation of ports. In the metaverse, risk scenarios could be simulated and security measures tested to assess their effectiveness before implementing them in real life. In addition, the metaverse could be used to monitor and detect potential security threats in real time, allowing for a quick and effective response to emergency situations.

In the customer and services block is the service quality sub-block, in terms of quality of service, the metaverse can be used to simulate different situations in which the port is used, including the handling of dangerous cargoes, the safety of people and equipment, and the efficiency of the loading and unloading process. By simulating these scenarios, potential problems and areas for improvement can be identified, which can help improve the quality of service at the port.

Overall, the use of the metaverse in ports and quality of service can provide a valuable tool to improve port efficiency, security, and profitability. However, it is important to note that the implementation of this technology is still under development and may require significant investment in terms of hardware, software, and staff training.

Based on the identification of driving elements for the transformation of Spanish ports into "metaports" by the panel of experts, several key conclusions can be drawn:

Technology and Digital Transformation: Technology and digital transformation are fundamental elements for the modernisation of Spanish ports. The adoption of advanced technologies, such as virtual reality, artificial intelligence, and automation, plays a crucial role in improving operational efficiency, safety, and sustainability.

Interoperability and Standards: The existence of standards and protocols in the sector is essential to ensure interoperability and system integration. This facilitates collaboration between different actors in the port and allows for the transfer of data and knowledge more effectively.

Education and Training: Training port staff in metaverse technologies is essential for the successful assimilation of these technologies. Adaptability and the ability to learn how to use these technologies are critical.

Cross-Sector Collaboration: Collaboration with other industries, such as aeronautics, can provide knowledge and expertise in adopting digital technologies. Collaboration and information sharing are key factors for success in port modernization.

Promotion Policies: The existence of policies and programs to promote the adoption of the metaverse in the sector is essential. These programs may include incentives and financial support for technological modernization.

Efficiency, Competitiveness and Sustainability: The modernization of ports not only seeks to improve efficiency and competitiveness, but also sustainability. Cost reduction, process optimization, and resource management are key elements in this transformation.

The transformation of Spanish ports into “metaports” involves significant investment in technology and training, as well as close collaboration between actors in the port sector and other related industries. Technological modernisation and the adoption of sustainable practices are key elements for the future of Spanish ports and their ability to compete internationally in an increasingly digital environment.

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References

Ahmad, H. F., Rafique, W., Rasool, R. U., et al. (2023). Leveraging 6G, extended reality, and IoT big data analytics for healthcare: A review. Computer Science Review, 48, 100558. https://doi.org/10.1016/j.cosrev.2023.100558

Allam, Z., Sharifi, A., Bibri, S. E., et al. (2022). The Metaverse as a Virtual Form of Smart Cities: Opportunities and Challenges for Environmental, Economic, and Social Sustainability in Urban Futures. Smart Cities, 5(3), 771–801. https://doi.org/10.3390/smartcities5030040

Batat, W. (2021). How augmented reality (AR) is transforming the restaurant sector: Investigating the impact of “Le Petit Chef” on customers’ dining experiences. Technological Forecasting and Social Change, 172, 121013. https://doi.org/10.1016/j.techfore.2021.121013

Bian, Y., Leng, J., & Zhao, J. L. (2022). Demystifying Metaverse as a New Paradigm of Enterprise Digitization. Lecture Notes in Computer Science, 109–119. https://doi.org/10.1007/978-3-030-96282-1_8

Bibri, S. E., Allam, Z., & Krogstie, J. (2022). The Metaverse as a virtual form of data-driven smart urbanism: Platformization and its underlying processes, institutional dimensions, and disruptive impacts. Computational Urban Science, 2(1), 24. https://doi.org/10.1007/s43762-022-00051-0

Bisht, D., Singh, R., Gehlot, A., et al. (2022). Imperative Role of Integrating Digitalization in the Firms Finance: A Technological Perspective. Electronics, 11(19), 3252. https://doi.org/10.3390/electronics11193252

Biswas, S., Sanyal, A., Božanić, D., et al. (2023). Critical Success Factors for 5G Technology Adaptation in Supply Chains. Sustainability, 15(6), 5539. https://doi.org/10.3390/su15065539

Buhalis, D., Papathanassis, A., & Vafeidou, M. (2022). Smart cruising: smart technology applications and their diffusion in cruise tourism. Journal of Hospitality and Tourism Technology, 13(4), 626–649. https://doi.org/10.1108/jhtt-05-2021-0155

Damar, M. (2021). Metaverse shape of your life for future: A bibliometric snapshot. Journal of Metaverse, 1(1), 1-8.

De Giovanni, P. (2023). Sustainability of the Metaverse: A Transition to Industry 5.0. Sustainability, 15(7), 6079. https://doi.org/10.3390/su15076079

de la Peña Zarzuelo, I., Soeane, M. J. F., & Bermúdez, B. L. (2020). Industry 4.0 in the port and maritime industry: A literature review. Journal of Industrial Information Integration, 20, 100173. https://doi.org/10.1016/j.jii.2020.100173

Deveci, M., Gokasar, I., Castillo, O., & Daim, T. (2022). Evaluation of Metaverse integration of freight fluidity measurement alternatives using fuzzy Dombi EDAS model. Computers & Industrial Engineering, 174, 108773. https://doi.org/10.1016/j.cie.2022.108773

Dincelli, E., & Yayla, A. (2022). Immersive virtual reality in the age of the Metaverse: A hybrid-narrative review based on the technology affordance perspective. The Journal of Strategic Information Systems, 31(2), 101717. https://doi.org/10.1016/j.jsis.2022.101717

Duan, H., Li, J., Fan, S., et al. (2021). Metaverse for Social Good: A University Campus Prototype. Proceedings of the 29th ACM International Conference on Multimedia, 153-161. https://doi.org/10.1145/3474085.3479238

Dutta, P., Choi, T.-M., Somani, S., & Butala, R. (2020). Blockchain technology in supply chain operations: Applications, challenges and research opportunities. Transportation research part e: Logistics and transportation review, 142, 102067.

Dwivedi, Y. K., Kshetri, N., Hughes, L., et al. (2023). Exploring the Darkverse: A Multi-Perspective Analysis of the Negative Societal Impacts of the Metaverse. Information Systems Frontiers, 1-44.

Fowlkes, C., Belongie, S., Fan Chung, & Malik, J. (2004). Spectral grouping using the nystrom method. IEEE Transactions on Pattern Analysis and Machine Intelligence, 26(2), 214–225. https://doi.org/10.1109/tpami.2004.1262185

Gadekallu, T. R., Wang, W., Yenduri, G., et al. (2023). Blockchain for the Metaverse: A review. Future Generation Computer Systems, 143, 401-419.

González-Cancelas, N., Camarero Orive, A., Espejo de Vena, R., & Soler Flores, F. (2022). Digitalisation Analysis of Land Transport Associated with Ports Using an Affinity Diagram (SSRN Scholarly Paper 4220855). https://doi.org/10.2139/ssrn.4220855

González-Cancelas, N., Vaca Cabrero, J., & Camarero Orive, A. (2023). Metaverse in Spanish ports as a high impact solution. pp. 1-19.

Gretzel, U., & Koo, C. (2021). Smart tourism cities: A duality of place where technology supports the convergence of touristic and residential experiences. Asia Pacific Journal of Tourism Research, 26(4), 352-364. https://doi.org/10.1080/10941665.2021.1897636

Hoyer, W. D., Kroschke, M., Schmitt, B., et al. (2020). Transforming the customer experience through new technologies. Journal of interactive marketing, 51(1), 57-71. https://doi.org/10.1016/j.intmar.2020.04.001

Huynh-The, T., Pham, Q.-V., Pham, X.-Q., et al. (2023). Artificial intelligence for the metaverse: A survey. Engineering Applications of Artificial Intelligence, 117, 105581.

Jauhar, S. K., Jani, S. M., Kamble, S. S., et al. (2023). How to use no-code artificial intelligence to predict and minimize the inventory distortions for resilient supply chains. International Journal of Production Research, 0(0), 1-25. https://doi.org/10.1080/00207543.2023.2166139

Kliestik, T., Nagy, M., & Valaskova, K. (2023). Global Value Chains and Industry 4.0 in the Context of Lean Workplaces for Enhancing Company Performance and Its Comprehension via the Digital Readiness and Expertise of Workforce in the V4 Nations. Mathematics, 11(3), 601. https://doi.org/10.3390/math11030601

Kye, B., Han, N., Kim, E., et al. (2021). Educational applications of metaverse: Possibilities and limitations. Journal of Educational Evaluation for Health Professions, 18, 32. https://doi.org/10.3352/jeehp.2021.18.32

Lin, C.-C., Yang, Z., & Chang, C.-H. (2022). Facilitating adoption of virtual communities through emotional connection in the global logistics industry. International Journal of Logistics Research and Applications, 1-19. https://doi.org/10.1080/13675567.2022.2153815

Lv, Z., Shang, W.-L., & Guizani, M. (2022). Impact of Digital Twins and Metaverse on Cities: History, Current Situation, and Application Perspectives. Applied Sciences, 12(24), 12820. https://doi.org/10.3390/app122412820

Mallam, S. C., Nazir, S., & Renganayagalu, S. K. (2019). Rethinking maritime education, training, and operations in the digital era: Applications for emerging immersive technologies. Journal of Marine Science and Engineering, 7(12), 428. https://doi.org/10.3390/jmse7120428

Maurya, M., Dixit, S., Zaidi, N., & Dharwal, M. (2022). The Phygital Dimension: Redefining Rules of Retail Success Through Technological Convergence. Evolution of Digitized Societies Through Advanced Technologies, 101–112. https://doi.org/10.1007/978-981-19-2984-7_9

Mhlanga, D. (2021). Artificial Intelligence in the Industry 4.0, and Its Impact on Poverty, Innovation, Infrastructure Development, and the Sustainable Development Goals: Lessons from Emerging Economies? Sustainability, 13(11), 5788. https://doi.org/10.3390/su13115788

Mourtzis, D., Panopoulos, N., Angelopoulos, J., et al. (2022). Human centric platforms for personalized value creation in metaverse. Journal of Manufacturing Systems, 65, 653-659. https://doi.org/10.1016/j.jmsy.2022.11.004

Mozumder, M. A. I., Armand, T. P. T., Imtiyaj Uddin, S. M., et al. (2023). Metaverse for Digital Anti-Aging Healthcare: An Overview of Potential Use Cases Based on Artificial Intelligence, Blockchain, IoT Technologies, Its Challenges, and Future Directions. Applied Sciences, 13(8), 5127. https://doi.org/10.3390/app13085127

Mozumder, M. A. I., Sheeraz, M. M., Athar, A., et al. (2022). Overview: Technology Roadmap of the Future Trend of Metaverse based on IoT, Blockchain, AI Technique, and Medical Domain Metaverse Activity. 2022 24th International Conference on Advanced Communication Technology (ICACT), 256-261. https://doi.org/10.23919/ICACT53585.2022.9728808

Neethirajan, S. (2023). Artificial Intelligence and Sensor Technologies in Dairy Livestock Export: Charting a Digital Transformation. Sensors, 23(16), 7045. https://doi.org/10.3390/s23167045

Ng, L. H. X., & Cruickshank, I. J. (2023). Recruitment promotion via Twitter: A network-centric approach of analyzing community engagement using social identity. Digital Government: Research and Practice, 4(4), 1–17. https://doi.org/10.1145/3617127

Perano, M., Cammarano, A., Varriale, V., et al. (2023). Embracing supply chain digitalization and unphysicalization to enhance supply chain performance: a conceptual framework. International Journal of Physical Distribution & Logistics Management, 53(5/6), 628–659. https://doi.org/10.1108/ijpdlm-06-2022-0201

Pooyandeh, M., Han, K.-J., & Sohn, I. (2022). Cybersecurity in the AI-Based Metaverse: A Survey. Applied Sciences, 12(24), 12993. https://doi.org/10.3390/app122412993

Qadir, A. M.-A., & Fatah, A. O. (2023). Platformization and the Metaverse: Opportunities and Challenges for Urban Sustainability and Economic Development. EAI Endorsed Transactions on Energy Web, 10(1). https://doi.org/10.4108/ew.3842

Qamar, S., Anwar, Z., & Afzal, M. (2023). A systematic threat analysis and defense strategies for the metaverse and extended reality systems. Computers & Security, 128, 103127. https://doi.org/10.1016/j.cose.2023.103127

Raza, Z., Woxenius, J., Vural, C. A., & Lind, M. (2023). Digital transformation of maritime logistics: Exploring trends in the liner shipping segment. Computers in Industry, 145, 103811. https://doi.org/10.1016/j.compind.2022.103811

Rejeb, A., Keogh, J. G., & Treiblmaier, H. (2019). Leveraging the Internet of Things and Blockchain Technology in Supply Chain Management. Future Internet, 11(7), 161. https://doi.org/10.3390/fi11070161

Romagnoli, S., Tarabu', C., Maleki Vishkaei, B., & De Giovanni, P. (2023). The Impact of Digital Technologies and Sustainable Practices on Circular Supply Chain Management. Logistics, 7(1), 1. https://doi.org/10.3390/logistics7010001

Secchi, C., & Gili, A. (2022). Digitalisation for sustainable infrastructure: The road ahead. Digitalisation for sustainable infrastructure, 1-326.

Singh, R., Akram, S. V., Gehlot, A., et al. (2022). Energy System 4.0: Digitalization of the Energy Sector with Inclination towards Sustainability. Sensors, 22(17), 6619. https://doi.org/10.3390/s22176619

Sopher, H., & Lescop, L. (2023). Learning in metaverse: the immersive atelier model of the architecture studio. Archnet-IJAR: International Journal of Architectural Research, 17(3), 536–553. https://doi.org/10.1108/arch-10-2022-0213

Tang, F., Chen, X., Zhao, M., & Kato, N. (2023). The Roadmap of Communication and Networking in 6G for the Metaverse. IEEE Wireless Communications, 30(4), 72–81. https://doi.org/10.1109/mwc.019.2100721

Templin, T., Popielarczyk, D., & Gryszko, M. (2022). Using Augmented and Virtual Reality (AR/VR) to Support Safe Navigation on Inland and Coastal Water Zones. Remote Sensing, 14(6), 1520. https://doi.org/10.3390/rs14061520

Wu, H., & Zhang, W. (2023). Digital identity, privacy security, and their legal safeguards in the Metaverse. Security and Safety, 2, 2023011. https://doi.org/10.1051/sands/2023011

Wylde, V., Prakash, E., Hewage, C., & Platts, J. (2023). Post-Covid-19 Metaverse Cybersecurity and Data Privacy: Present and Future Challenges. Data Protection in a Post-Pandemic Society, 1–48. https://doi.org/10.1007/978-3-031-34006-2_1

Yao, X., Ma, N., Zhang, J., et al. (2022). Enhancing wisdom manufacturing as industrial metaverse for industry and society 5.0. Journal of Intelligent Manufacturing. https://doi.org/10.1007/s10845-022-02027-7

Yoon, D., & Oh, A. (2022). Design of Metaverse for Two-Way Video Conferencing Platform Based on Virtual Reality. Journal of Information and Communication Convergence Engineering, 20(3), 189–194. https://doi.org/10.56977/jicce.2022.20.3.189

Zhang, H., Luo, G., Li, Y., & Wang, F.-Y. (2022). Parallel vision for intelligent transportation systems in metaverse: Challenges, solutions, and potential applications. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 53(6), 3400–3413. https://doi.org/10.1109/tsmc.2022.3228314