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METODOLOGIA PARA AVALIAR NÍVEL DE MATURIDADE DA INDUSTRIA 4.0 E SUA CORRELAÇÃO COM ATRIBUTOS DO METAVERSO INDUSTRIAL

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ABSTRACT
Since Facebook changed its name to Meta, a term has been growing and becoming widespread in the industrial sectors: Industrial Metaverse. Understanding this term and how to use the tools proposed by these new technologies to increase sales, optimize resources, and increase productivity can be a key factor in determining the survival or failure of a given business. In this sense, establishing a methodology (easy and accessible for all levels of companies, from small to medium and large) that could help companies identify the current maturity levels for each of the Industry 4.0 tools that are relevant to developing applications in the metaverse in the future is the main objective of this study. To this end, a bibliographic review was carried out to establish and define which would be these main enabling tools of Industry 4.0, and based on this information and the definition of the attributes of the Metaverse by Weinberg and Gross (2023), a correlation table was prepared to serve as a guide in preparing the bases in these companies to support the development of applications in the metaverse, if they wish. Using this proposed

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methodology, an assessment was made of a company with one of its branches located in the city of Manaus. Through an internal document review of this company, it was possible to assess the maturity level of these Industry 4.0 tools and, through correlation with the metaverse attributes, it was defined which points should be the focus of actions to improve and establish the necessary bases to support application initiatives in the metaverse in the future.

Keywords: Metaverse. Attributes. Industry 4.0. Maturity.

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INTRODUCTION

The concept of the metaverse is emerging as one of the most revolutionary technologies of the digital age, enabling immersive and interactive experiences that transcend the physical world. The metaverse refers to a shared virtual space created by the convergence of virtual reality (VR) and augmented reality (AR) where users can interact with each other and with digital environments in a highly engaging way ( ). In the context of Industry 4.0, the metaverse has the potential to radically transform project management and decision-making by integrating virtual and physical environments to improve efficiency and collaboration. Industry 4.0 is characterized by advanced automation, data exchange, and emerging technologies such as artificial intelligence (AI), the Internet of Things (IoT), and cloud computing. The metaverse adds a new dimension to this revolution by enabling the creation of virtual environments where teams can collaborate in real-time, simulate production processes, and make decisions based on integrated data. This advancement is crucial for companies seeking to maintain competitiveness and continuous innovation. The metaverse enables the visualization and manipulation of complex data in an immersive environment, facilitating the identification of problems and the making of quick and accurate decisions (Cali et al., 2022).

The concept of the metaverse gained prominence with the development of virtual and augmented reality platforms, such as Second Life and, more recently, Facebook Horizon. These platforms paved the way for the exploration of interactive virtual environments, where users can create and share digital experiences. In Industry 4.0, the integration of the metaverse began to be explored as a way to simulate smart factories, train employees in virtual environments, and improve global collaboration. Research indicates that the metaverse can significantly improve communication and coordination between geographically dispersed teams, in addition to providing a safe environment for testing and validating new solutions (Sousa et al., 2015).

Despite the growing interest in the metaverse, there is still little research focused on its specific application in Industry 4.0, particularly in defining a methodology to help companies start using this technology. This study seeks to fill this gap by proposing a simple and accessible methodology for companies of different sizes to assess their maturity levels with Industry 4.0 enabling tools. Based on this assessment, we hope to provide clear guidance on where to invest resources to develop applications in the metaverse and enjoy its potential benefits.

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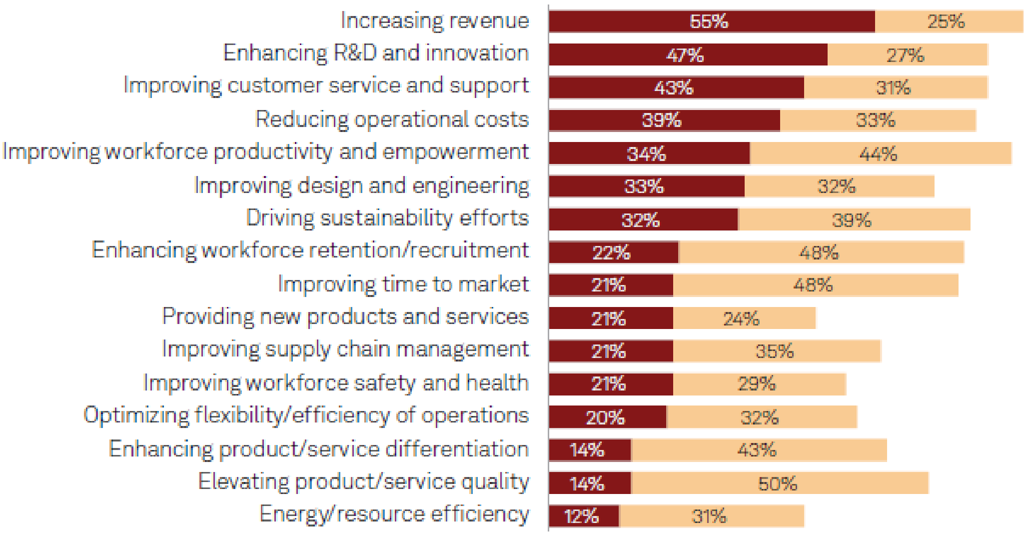
Figure 1 - Level of impacts perceived on business after using the Metaverse



Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

To achieve this goal, a comprehensive literature review was conducted to identify the main Industry 4.0 tools and correlate them with the metaverse attributes defined by Weinberg and Gross (2023). The proposed methodology was applied to a company with a branch in Manaus, enabling a detailed assessment of the maturity level of these tools. The results obtained indicated critical points for investment focus and developed the basis for future initiatives in the industrial metaverse.

THEORETICAL FRAMEWORK

INDUSTRY 4.0

Industry 4.0, officially introduced in 2011 at the Hannover Fair, represents the fourth industrial revolution and is marked by the convergence of digital technologies and industrial operations (Drath & Horch, 2014). This concept seeks to increase productivity and efficiency through the application of technological solutions such as IoT, cloud computing, big data, and artificial intelligence (Frank et al., 2019a).

The focus of Industry 4.0 is the digital transformation of production processes, connecting the virtual world to the real world. This enables automated factories to evolve into smart and connected factories, characterized by the use of cyber-physical systems (Benitez et al., 2020). Such systems allow the integration of sensors, smart devices, and real-time analysis platforms, promoting greater flexibility and efficiency in production.

In addition, Industry 4.0 employs technologies such as augmented reality, simulation, and advanced robotics, which expand its operational capabilities (Dalenogare

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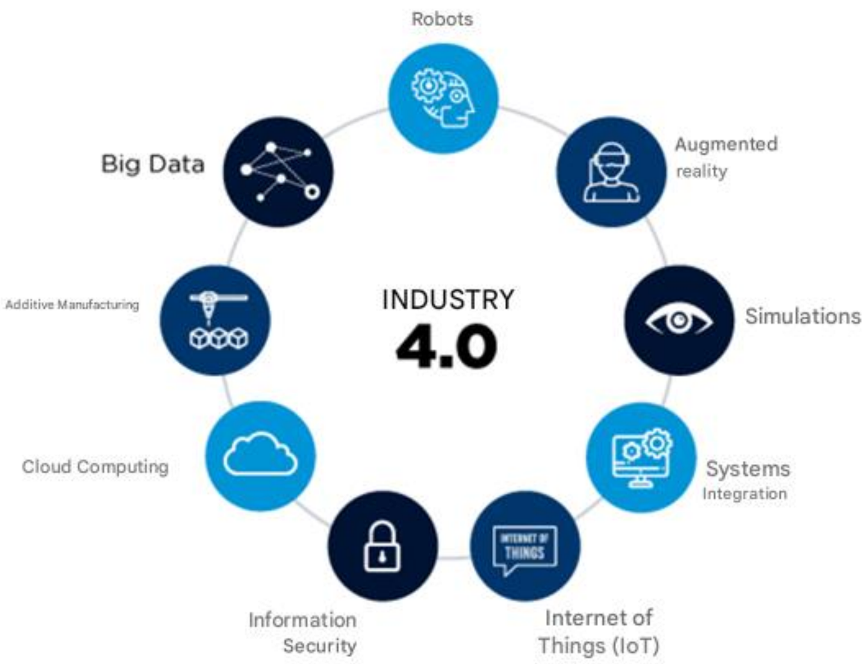
et al., 2019a). Artificial intelligence also plays a vital role, in optimizing processes, predicting failures, and personalizing products (Artero, 2023). This technological ecosystem not only increases productivity but also paves the way for significant innovations.

In short, Industry 4.0 is redefining the global industrial landscape by integrating advanced technologies and creating smarter and more connected factories. This makes it possible to explore new business models and growth opportunities, which are essential for competitiveness in increasingly demanding markets.

Figure 2 – Industry 4.0 core technologies



Source: Chesini, 2023

CONVERGENCE OF THE METAVERSE WITH INDUSTRY 4.0

The concept of the metaverse, which dates back to Neal Stephenson's novel "Snow Crash" (1992), has evolved from simple virtual worlds to a more complex ecosystem, encompassing education, healthcare, and industry (Mystakidis, 2022). This evolution was possible thanks to the convergence of technologies such as IoT, big data, and 5G networks, which provided the necessary infrastructure for highly interactive virtual environments (Lee et al., 2024).

In Industry 4.0, this convergence allows companies to create detailed virtual representations of their production processes. For example, Volkswagen uses the metaverse to simulate production scenarios and train employees, while Siemens employs similar technologies for predictive maintenance, integrating IoT sensors into its equipment (Volkswagen, 2022; Siemens, 2021). These cases highlight how the metaverse and Industry 4.0 complement each other, improving operational efficiency and fostering innovation.

The integration of the metaverse also extends to global collaboration, as demonstrated by General Electric (GE), which implemented virtual environments for its engineering teams to work on complex projects, regardless of geographic location (General Electric, 2020). These examples illustrate the revolutionary potential of the metaverse in industry, pointing to a future in which virtual and physical technologies are fully integrated, facilitating processes, increasing productivity, and improving collaboration.

ENABLING TOOLS FOR INDUSTRY 4.0

Industry 4.0 enabling tools play a crucial role in the integration and automation of production processes. These technologies include IoT, which connects devices and systems, enabling the collection and analysis of data in real-time (Zhou et al., 2015), and big data, which facilitates the analysis of large volumes of information for more informed decision-making (Manyika et al., 2011).

Another key technology is artificial intelligence (AI), which enables the automation of complex tasks and the personalization of products based on data (Kaplan & Haenlein, 2019). Advanced robotics, in turn, improves precision and efficiency in production, while additive manufacturing, such as 3D printing, enables the creation of rapid prototypes and on-demand production (Gibson et al., 2015).

In addition, cloud computing enables remote access to data and applications, promoting collaboration and operational efficiency (Armbrust et al., 2010). These technologies, when integrated, create a digital ecosystem that transforms industrial operations, allowing for greater flexibility and responsiveness to market demands.

Together, these enabling tools lay the foundation for the implementation of the metaverse in industry, providing an integrated virtual environment where simulations, analyses, and collaborations can occur in real-time, optimizing productivity and promoting disruptive innovations.

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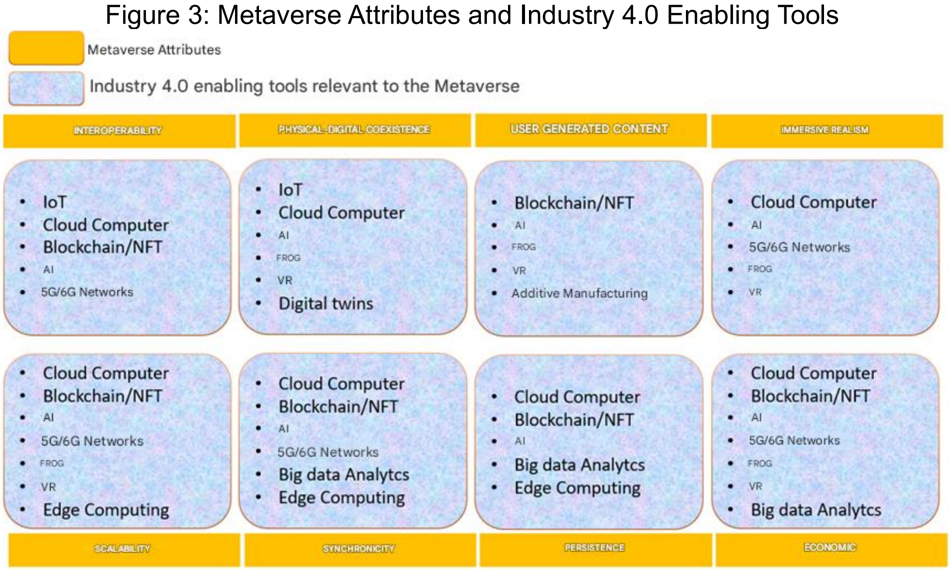
ATTRIBUTES OF THE METAVERSE AND ITS RELATIONSHIP WITH INDUSTRY 4.0

The metaverse is composed of a series of attributes that differentiate it from other immersive technologies. Among these attributes, immersion, interactivity, and persistence stand out (Weinberg & Gross, 2023). Immersion refers to the ability to create a realistic sense of presence in a virtual environment, while interactivity involves the possibility of real-time interaction between users and digital objects. Persistence ensures that the virtual environment continues to exist and evolve regardless of the presence of users.

In Industry 4.0, these attributes have significant applications. For example, immersion can be used to create realistic simulations of production lines, allowing employee training without risk to the real environment. Interactivity facilitates real-time collaboration between teams located in different parts of the world, while persistence allows continuous monitoring of processes and data collection for future analysis (Cali et al., 2022).

These attributes also contribute to the creation of digital twins, which are virtual representations of physical assets, processes, or systems. Digital twins allow companies to monitor and optimize their operations in real-time, using data collected from IoT sensors to simulate different scenarios and predict potential failures (Benitez et al., 2020). This combination of metaverse attributes with Industry 4.0 technologies is transforming the way companies plan and execute their operational strategies, increasing efficiency and promoting innovation. Figure 3 below shows this interaction between Industry 4.0 enabling tools and metaverse attributes.

Figure 3: Metaverse Attributes and Industry 4.0 Enabling Tools



Source: Prepared by the author, 2024

DIGITAL TWINS AS THE BASIS FOR THE INDUSTRIAL METAVERSE

Digital twins are emerging as one of the main pillars of the industrial metaverse, providing detailed virtual representations of physical assets and processes. These digital models allow companies to monitor, analyze, and optimize operations in real-time, using data collected by IoT sensors (Grieves & Vickers, 2017). In addition, digital twins offer a secure platform for simulations and testing, reducing costs and risks associated with changes in production processes (Tao et al., 2019).

In practice, companies such as General Electric (GE) have adopted digital twins to predict equipment failures, improve energy efficiency, and optimize predictive maintenance (General Electric, 2020). These advances are revolutionizing the way organizations manage their assets, enabling greater precision in decision-making and promoting sustainability.

Furthermore, digital twins facilitate the creation of collaborative environments, where teams can work together on complex projects, even when geographically dispersed. This is particularly relevant in the context of the industrial metaverse, where integration between the virtual and physical worlds is essential for the success of innovative initiatives (Cali et al., 2022).

CHALLENGES AND PROSPECTS FOR THE METAVERSE IN INDUSTRY 4.0

Despite the great potential of the metaverse in Industry 4.0, its implementation faces several challenges. One of the main obstacles is the high dependence on robust technological infrastructure, such as 5G networks and high-capacity cloud computing systems. In addition, the integration between legacy systems and new technologies represents a significant challenge for many organizations (Tao et al., 2021).

Another critical point is information security. The constant exchange of sensitive data in virtual environments increases the risk of cyberattacks, requiring companies to invest in advanced cybersecurity solutions. In addition, there is a need for training and qualification of employees so that they can operate in immersive and interactive environments, which requires cultural changes and investments in corporate education (Weinberg & Gross, 2023).

However, the prospects for the metaverse in Industry 4.0 are promising. The continuous evolution of enabling technologies, such as artificial intelligence and the Internet of Things, promises to solve many of the current challenges. Additionally, the creation of international standards and regulations can facilitate interoperability between systems and ensure data security and privacy.

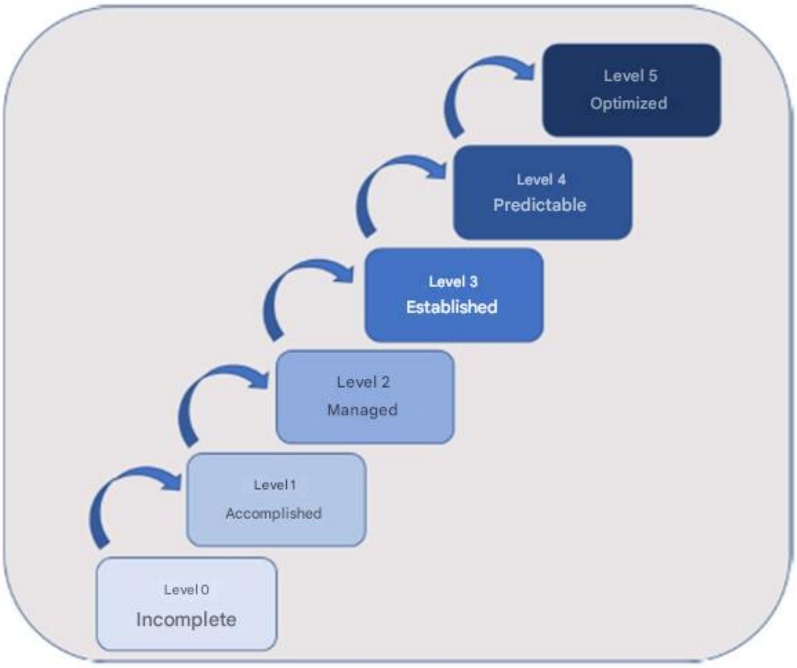
In the medium and long term, the industrial metaverse is expected to promote global collaboration at unprecedented levels, allowing companies to develop new business models and explore as yet unexplored markets. In this way, the metaverse can become an essential tool for innovation and competitiveness in the global industrial scenario.

MATURITY MODEL OF INDUSTRY 4.0 ENABLING TOOLS

To define the maturity level, we used as a reference the work carried out by Schneider (2018), which was based on the study of the Gokalp model (2017), as we identified that this simpler approach can enable the implementation of this model even in small and medium-sized companies due to its simplicity.

This study defines the assignment of a score according to the stage of application of each tool. This score can vary from 0 to 5, where zero means that the company does not use any of that tool in its activities and operations and 5 would be the highest level, indicating that the tool can have a degree of self-learning, monitoring, and management of its information. Figure 4 below shows the Maturity Levels model presented in the Work of Scheiner (2018).)

Figure 4: Maturity Levels



Source: Schneider, 2018.

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Going a little deeper into this model, we explain below a little more about the classification logic of each level:

a) Level 0: Incomplete. There is no implementation yet. The organization only focuses on fundamental operations, such as requirements analysis, acquisition, production, and sales.

b) Level 1: Completed. The transformation has begun. The technological infrastructure for the transition to Industry 4.0 has been acquired and the organization tends to employ smart technologies such as IoT (Internet of Things). The vision of Industry 4.0 exists and is also a roadmap for the transition strategy, but it is not fully implemented.

c) Level 2: Managed. The data set related to each operation is defined and has begun to be collected, but it is not integrated into the different functionalities of the operations. Physical items are beginning to be represented by a virtual world.

d) Level 3: Established. The main business activities and value-added operations are well-defined and the qualifications of processes and operations are consistent with the corresponding standardization. The data set is identified for each operation in the organization and systematically collected and stored in a well-managed database. Vertical integration, including the in-plant integration of sensors and actuators within machines up to enterprise resource planning systems, has been achieved.

e) Level 4: Predictable. Horizontal integration, including the integration of production networks at the business level, is achieved by supply chain integration but may include more in the future when real-time and product- or process-specific information is exchanged to increase the level of detail and quality in distributed manufacturing optimization. Data analysis tools are employed to improve manufacturing productivity.

f) Level 5: Optimization. Integration for engineering and product/production lifecycle has been achieved to enable low-effort knowledge sharing and synchronization between product and service development and manufacturing environments. The organization begins to learn from the collected data and tries to improve its business continuously. The business model is evolving into an innovative structure (GÖKALP et al., 2017). Figure 5 below shows a summary of the criteria that can be used to classify the implementation levels of enabling tools according to the work of Gokalp et al (2017).)

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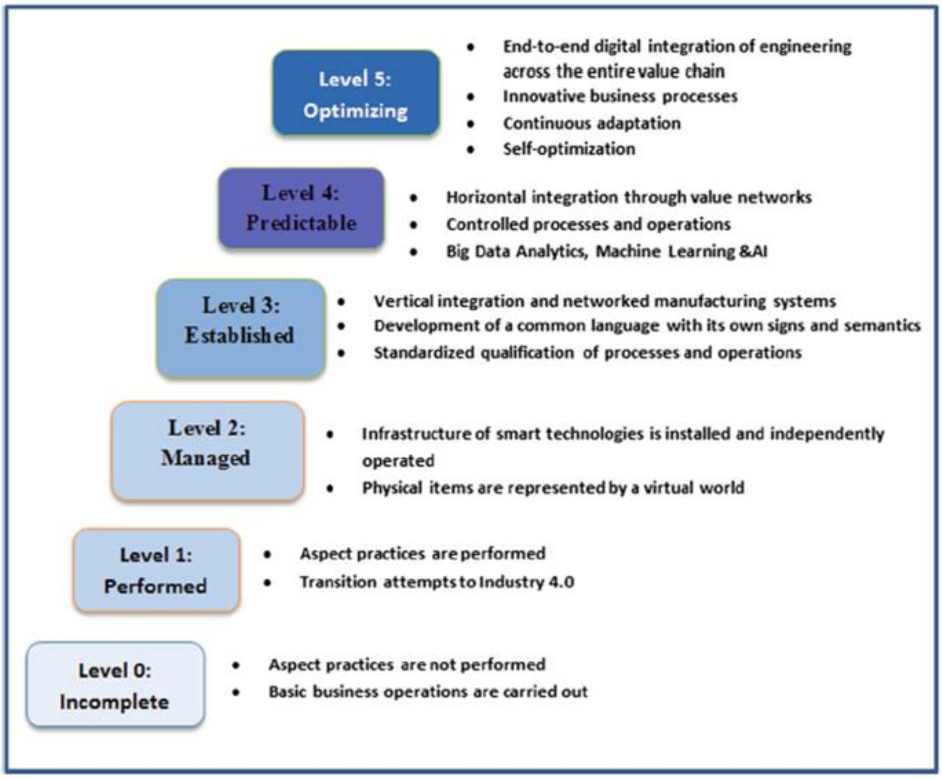
Figure 5: Details of each maturity level



Source: Gokalp et al (2017)

METHODOLOGY

PROPOSED MATURITY MODEL OF THE METAVERSE BASED ON THE ENABLING TOOLS OF INDUSTRY 4.0

According to the interrelationships described above between the tools of Industry 4.0 and the basic attributes of the metaverse, it is possible to define which Industry 4.0 tools have the most impact on each of the essential characteristics of the metaverse. Table 2 describes the intercorrelations between Industry 4.0 tools and the attributes of the Metaverse to make it easier to identify the interdependence of the Metaverse with the enabling tools of Industry 4.0.

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Table 2: Correlation matrix between the metaverse characteristics and Industry 4.0 tools

METAVERSE / INDUSTRY 4.0	IoT	Cloud Computing	Blockchain / NFT	AI	5G Networks	AR	VR	Digital Twins	Additive Manufacturing	Big Data Analytics	Edge Computing
Interoperability	X	X	X	X	X						
Physical/Digital Coexistence	X	X		X	X	X	X				
User-Generated Content		X	X	X	X	X		X			
Immersive Realism		X	X	X	X	X					
Scalability		X	X	X	X	X	X		X		
Synchronicity		X	X	X			X		X		
Persistence		X	X						X		
Economic		X	X	X	X	X					X

Source: Created by the author, 2024.

CLASSIFICATION OF THE IMPLEMENTATION LEVEL OF INDUSTRY 4.0 TOOLS

Table 3 presents the implementation level scores for the main Industry 4.0 tools that are extremely relevant for implementing metaverse applications, according to the bibliographic review of this work. After surveying the maturity levels of each of these tools, we will transfer this information into the correlation table between the enabling tools of Industry 4.0 and the table of key attributes that make up the so-called metaverse.

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Table 3: Implementation level score of Industry 4.0 tools

Industry 4.0 Basic Tools for the Metaverse	Score	0	1	2	3	4	5
IoT		X					
Cloud Computing		X					
Blockchain/NFT		X					
AI		X					
5G Networks		X					
AR		X					
VR		X					
Physical/Digital Coexistence		X					
Additive Manufacturing		X					
Big Data Analytics		X					
Edge Computing		X					

Source: Adapted from SCHNEIDER (2018).

METAVERSE MATURITY LEVEL

By surveying the stages of implementation of the Industry 4.0 tools, we will be able to visualize which metaverse attributes have the best and greatest chances of being leveraged and, therefore, developed within the organization. To do this, we will use the correlation table created in the previous chapter and include in it all the scores that each of the enabling tools of Industry 4.0 have been classified with, as shown in the filled Table 4 below:

Table 4: Example of the implementation level score of Industry 4.0 tools obtained

METAVERSE / INDUSTRY 4.0	IoT	Cloud Computing	Blockchain / NFT	AI	5G Networks	AR	VR	Digital Twins	Additive Manufacturing	Big Data Analytics	Edge Computing
Interoperability	X1	X2	X3	X4	X5						
Physical/Digital Coexistence	X1	X2		X4	X6	X7	X8				
User-Generated Content		X3	X4	X6	X7			X9			
Immersive Realism		X2	X4	X5	X6	X7					
Scalability		X2	X3	X4	X5	X6	X7		X11		
Synchronicity		X2	X3	X4	X5		X10	X11			
Persistence		X2	X3	X4				X10	X11		
Economic		X2	X3	X4	X5	X6	X7		X10		X10

Source: Created by the author, 2024.

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After we include all the information about the maturity level of Industry 4.0 tools, we will add a column at the end that will sum all the values we assigned to each Industry 4.0 tool. This will show us the total points for each metaverse attribute being evaluated. As demonstrated in the example in Table 5, showing subtotals for each metaverse attribute:

Table 5 – Subtotals obtained for metaverse attributes

METAVERSE / INDUSTRY 4.0	TOTAL
Interoperability	=X1+X2+X3+X4+X5
Physical/Digital Coexistence	=X1+X2+X4+X6+X7+X8
User-Generated Content	=X3+X4+X6+X7+X9
Immersive Realism	=X2+X4+X5+X6+X7
Scalability	=X2+X3+X4+X5+X6+X7+X11
Synchronicity	=X2+X3+X4+X5+X10+X11
Persistence	=X2+X3+X4+X10+X11
Economic	=X2+X3+X4+X5+X6+X7+X10
Source: Prepared by the author, 2024	

Next, we will divide each of these results for the sums of each attribute by the number of times "X" appears in the correlation table. This number will be the number of Industry 4.0 tools relevant to the particular metaverse attribute being analyzed, as shown in Table 6 below:

Table 6 – Total of averages obtained for classifying the company's maturity level for the metaverse

METAVERSE / INDUSTRY 4.0	TOTAL	Nº Relevant Industry 4.0 Tools	Maturity Level of Metaverse Attributes
Interoperability	=X1+X2+X3+X4+X5	5	=(X1+X2+X3+X4+X5)/5
Physical/Digital Coexistence	=X1+X2+X4+X6+X7+X8	6	=(X1+X2+X4+X6+X7+X8)/6
User-Generated Content	=X3+X4+X6+X7+X9	5	=(X3+X4+X6+X7+X9)/5
Immersive Realism	=X2+X4+X5+X6+X7	5	=(X2+X4+X5+X6+X7)/5
Scalability	=X2+X3+X4+X5+X6+X7+X11	7	=(X2+X3+X4+X5+X6+X7+X11)/7
Synchronicity	=X2+X3+X4+X5+X10+X11	6	=(X2+X3+X4+X5+X10+X11)/6
Persistence	=X2+X3+X4+X10+X11	5	=(X2+X3+X4+X10+X11)/5
Economic	=X2+X3+X4+X5+X6+X7+X10	7	=(X2+X3+X4+X5+X6+X7+X10)/7
Source: Prepared by the author, 2024			

By doing this, we will be able to see which attributes, important for starting the development of applications in the metaverse, need to be strengthened. From here, we can start to have a "guideline" of where the company could direct more investments to establish a solid base of tools for starting metaverse application development.

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SCOPE DEFINITION AND REQUIREMENTS GATHERING

The metaverse represents an immersive virtual environment where the physical and digital worlds integrate into continuous experiences. In the context of creating and developing projects in the metaverse, scope definition is a crucial step. Just like in traditional projects, scope involves clearly outlining objectives, deliverables, tasks, and constraints. However, the unique characteristics of the metaverse require special attention, as it incorporates elements of augmented reality, virtual reality, blockchain, and other emerging technologies.

A well-defined scope in the metaverse is essential to ensure that project goals are achieved efficiently, without wasting resources. The innovative and rapidly evolving nature of the metaverse makes it crucial to constantly review and adjust the scope to keep up with technological changes and user expectations. Projects in the metaverse require an agile approach, where the scope is treated as a living document, adaptable to emerging demands.

Developing projects in the metaverse brings new challenges and opportunities in terms of scope definition. The complexity of the involved technologies, the potential for new economic models, and privacy and security issues make this process more dynamic and critical. Defining a clear and flexible scope is vital to ensure the success of initiatives within the metaverse.

Within the scope gathering process, we will use a methodology to identify the current maturity level within the organization for implementing Industry 4.0 technologies, considered enabling technologies for implementing tools and utilizing the metaverse in these organizational activities.

Performing an analysis of strengths and weaknesses will be used to identify the current strong and weak points, which will help us define and prioritize which technologies and investments could be made to decide in which areas and activities we could apply the metaverse within the organization. This will always be done by considering the company's expectations and interests, as well as identifying the metaverse maturity level the company aims to achieve.

To define this metaverse maturity level, we use as a reference the work of Weinberger and Gross (2023), which defines the key attributes of the metaverse and some metrics for determining its maturity level.

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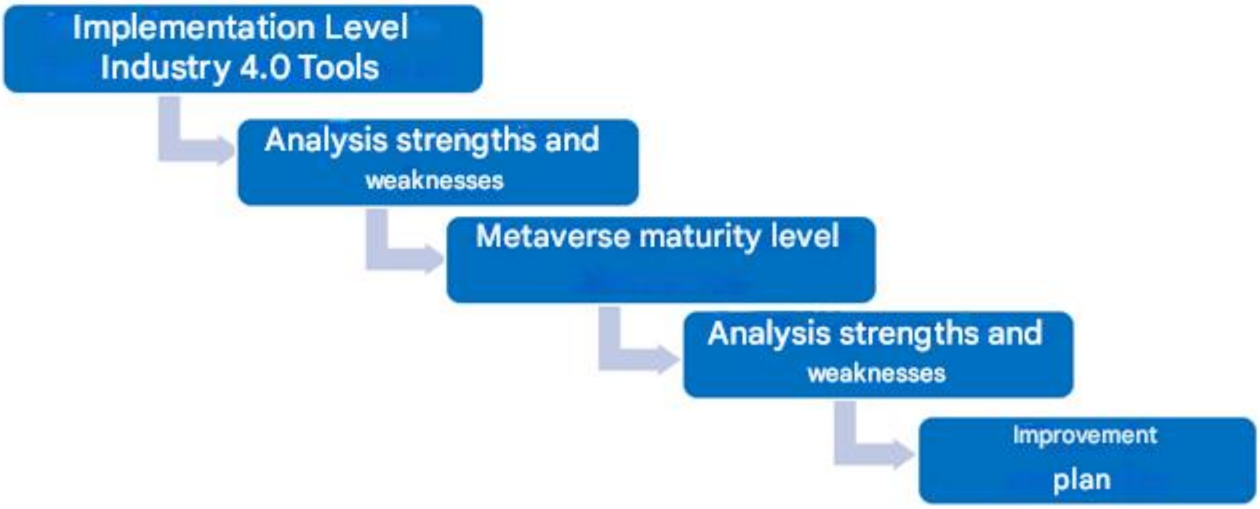
In the next chapter, we will elaborate more on the relationships between the enabling tools of Industry 4.0 and the main attributes that make up the metaverse, as this will serve as the basis for the final analysis of strengths and weaknesses within the company.

IMPLEMENTATION GUIDELINES

In summary, we could define the following steps as a kind of roadmap that organizations wishing to use metaverse applications could follow to better define which types of metaverse applications could be employed/developed within their operations to optimize their resources and investments, as shown in Figure 6:

1. Gathering the level of implementation of Industry 4.0 tools already used by the company.
2. Analyzing the strengths and weaknesses of Industry 4.0 tools.
3. Gathering the maturity level of the attributes that make up the metaverse.
4. Analyzing the strengths and weaknesses of metaverse attributes to identify the areas the organization needs to improve to have a stronger base of tools for starting metaverse application development.
5. Defining the implementation plan (where to invest) to strengthen the necessary foundations for metaverse application development, optimizing the company's existing strengths and, if necessary, improving some of its weaknesses with suggested KPIs.

Figure 6 – Step by step methodology



Source: Prepared by the author, 2024

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RESULTS AND DISCUSSION

CHARACTERIZATION OF THE COMPANY IN THE CASE STUDY

The company analyzed in the case study is located in the Industrial Hub of Manaus and operates in the audio sector. It is a privately held multinational corporation with operations in several regions of the world, developing audio, video, and connected solutions such as connected cars and IoT services. The organization employs approximately 30,000 people and offers products ranging from headphones to sound systems for stadiums and cinemas. The company invests in mobile connectivity, OTA (over-the-air) technologies, and solutions such as 3D navigation and support for smart applications. Its strategy is aligned with sustainability and social responsibility.

ANALYSIS OF THE MATURITY LEVEL OF IMPLEMENTATION OF INDUSTRY 4.0 TOOLS

The first step of this methodology is precisely to assess the maturity level of each of these enabling tools of Industry 4.0 within organizations.

A documentary survey was conducted, which highlighted the level of each of the enabling tools of Industry 4.0 relevant from the perspective of metaverse attributes. The table below shows the score obtained by each of these tools in the company where this study was conducted:

Table 7 – Implementation level of Industry 4.0 tools in the case study company

Relevant Industry 4.0 Tools for the Metaverse	IoT	Cloud Computing	Blockchain /NFT	AI	5G Networks	AR	VR	Physical Digital Coexistence	Additive Manufacturing	Big Data Analytics	Edge Computing
	4	5	2	5	4	2	2	2	1	5	4

Source: Prepared by the author, 2024

RESULTS OF THE MATURITY ASSESSMENT OF INDUSTRY 4.0 TOOLS

The maturity assessment of Industry 4.0 tools, based on this specific model, considered indicators such as connectivity, automation, and data integration. The results showed that the company has intermediate maturity in tools like IoT and big data, but has gaps in areas such as virtual reality and digital twins.

From the radar chart, it is possible to see that there are some weak points that need to be

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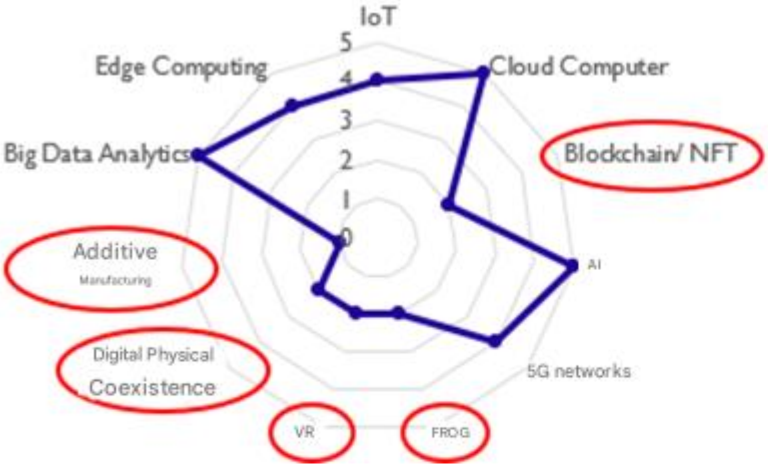
developed to improve the company's ability to have more technological foundation in the future to develop metaverse-based applications within the company studied. Among the weakest points are:

- Blockchain / NFT
- Additive Manufacturing
- Virtual Reality
- Augmented Reality

Figure 7: Implementation level of Industry 4.0 enabling tools



Source: Prepared by the author, 2024

These gaps were identified as critical points for future development, especially in the implementation of immersive technologies. The analysis highlighted that, although the company already has well-established processes, there is a need for greater integration of real-time data and investments in technological infrastructure to support the use of the metaverse.

ANALYSIS OF THE MATURITY LEVEL OF IMPLEMENTATION OF INDUSTRY 4.0 TOOLS CORRELATED WITH METAVERSE ATTRIBUTES

Following the methodology and inputting the scores in Table 8, which correlates the enabling tools of Industry 4.0 with the attributes of the metaverse, the following scoring table is produced:

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Table 8: Correlation between metaverse characteristics and enabling tools of Industry 4.0

	IoT	Cloud Computing	Blockchain/NFT	AI	5G Networks	AR	VR	Digital Twins	Additive Manufacturing	Big Data Analytics	Edge Computing	Average
Interoperability	4	5	2	5	4							4.00
Physical/ Digital Coexistence	4	5		5		2	2	2				3.33
User-Generated Content			2	5		2	2					2.40
Immersive Realism		5		5	4	2	2					3.60
Scalability		5	2	5	4	2	2		4			3.43
Synchronicity		5	2	5			5	4				4.17
Persistence		5	2	5				5	4			4.20
Economic		5	2	5	4	2	2		5			3.57

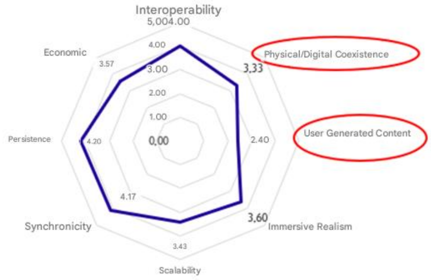
Source: Prepared by the author, 2024

RESULTS OF THE MATURITY ASSESSMENT OF METAVERSE ATTRIBUTES

From the radar chart analysis shown in Figure 8, it can be highlighted that the two least present metaverse attributes in the applications that are currently being implemented and used by the company in this case study are:

- User-generated content
- Physical and Digital Coexistence

Figure 8: Maturity level of metaverse attributes in the case study company



Source: Prepared by the author, 2024

RECOMMENDATION PLAN

Based on the information from the graphs collected above, we have the following information:

a) 4 Industry 4.0 enabling tools that proved to be weaknesses of the organization:

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o Block chain / NFT;

o Additive Manufacturing;

o Virtual Reality;

o Augmented Reality

b) 2 Metaverse attributes that were also pointed out as weaknesses of the organization:

o User-generated content

o Physical and Digital Coexistence

By correlating the 2 lowest values of the implementation level of the Industry 4.0 enabling tools and the 2 lowest values obtained in the analysis of the metaverse attributes, we have as our main output table 9 below.:

Table 9: Correlation between weak metaverse features and less developed Industry 4.0 enabling tools

	Blockchain/ NFT	RA	RV	Digital Twins	Manufatura Aditiva	Average
Physical/Digital Coexistence		2	2	2		3,33
User Generated Content	2	2	2		1	2,40

Source: Prepared by the author, 2024

Through this table, we can see that the company under study, if it intends to start developing applications involving the metaverse, could start investing resources to develop more technologies/processes/products that involve the development of applications using augmented reality and virtual reality, since the two tools have a lot of significance in relation to the two least perceived attributes in the organization in which this case study was carried out.

Based on the final results obtained, demonstrated above, a plan of recommendations was generated in several areas where investments could be made to increase the degree of use and application of both augmented reality and virtual reality within this organization, as shown in figures 10 and 11 below.:

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Table 10: AR Recommendations Plan

Investment Area	Investment Actions
1. Infrastructure and Equipment	Display Devices: Invest in smartphones, tablets, AR glasses (such as HoloLens or Magic Leap), or specialized devices that support the technology.
	Sensors and Cameras: Acquire equipment that increases AR accuracy, such as 3D cameras or motion sensors.
2. Software Development	AR Platforms: Use tools like Unity, Unreal Engine, or Vuforia to develop custom applications.
	In-House Development: Build a development team to create solutions tailored to your business needs.
	Third-Party Apps: Hire companies specialized in AR to create custom applications.
3. Team Training	Training: Train your team to understand and operate AR tools.
	Workshops: Offer internal workshops for employees to explore the potential of the technology.
4. Interactive Content	Experience Design: Create engaging content like interactive simulations, AR tutorials, or product demonstrations.
	Data Integration: Combine AR with data analytics to provide real-time insights.
5. Customer Experience	Product Demonstration: Use AR to show how products work or would look in the customer's space.
	Virtual Try-Ons: Allow customers to try on clothes, furniture, or other products virtually.
6. Marketing and Promotion	Creative Campaigns: Use AR in marketing campaigns to create immersive experiences.
	Gamification: Create AR games or challenges to attract new customers.
7. Collaboration with Partners	Technological Partnerships: Collaborate with startups or tech companies to implement innovative solutions.
	Innovation Ecosystem: Participate in AR events or communities to exchange knowledge and explore trends.

Table 11: VR Recommendations Plan

Investment Area	Investment Actions
1. Infrastructure and Equipment	Virtual Reality Headsets: Invest in devices like Oculus Quest, HTC Vive, Pico, or others that match your needs.
	Support Hardware: Ensure computers and servers have sufficient graphic capacity to run high-quality VR applications.
	Complementary Accessories: Purchase controllers, sensors, simulation treadmills (such as Omni One), and 360° cameras.
2. Application Development	Custom Software: Develop VR applications tailored to your needs, such as simulations, training, project visualization, or immersive marketing.
	Development Platforms: Use tools like Unity, Unreal Engine, or Blender to create environments and experiences.
	Partnerships with Experts: Hire developers or agencies specialized in creating custom VR solutions.
3. Team Training and Education	Internal Training: Teach employees how to operate VR devices and applications.
	Workshops: Organize practical sessions to explore VR's potential in different business areas.
	Hiring Specialists: Hire or outsource professionals specialized in VR design and programming.
4. Immersive Experiences	Product Demonstrations: Create VR experiences that allow customers to explore your products interactively.
	Training and Simulations: Use VR for training in controlled scenarios, such as workplace safety, complex operations, or customer service.
	Virtual Prototyping: Implement VR to visualize prototypes and designs before advancing to production.

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5. Business Applications	Engineering and Construction: Use VR to create and review 3D models of projects before execution.
	Healthcare: Implement VR for training medical teams or simulating surgeries.
	Education and Training: Develop immersive learning programs for employee training.
6. Marketing and Customer Experience	Interactive Campaigns: Develop VR marketing initiatives to attract customers with innovative experiences.
	Virtual Stores: Offer VR tours to showcase products, services, or environments in an immersive way.
	Events and Trade Shows: Use VR to create interactive booths or impactful presentations.
7. Collaboration and Remote Work	Virtual Meetings: Implement VR platforms like Spatial or Horizon Workrooms for immersive meetings and collaborations.
	Scenario Simulations: Conduct simulations of operations or decision-making in virtual environments.
8. Research and Development	Experimentation: Create internal labs to test the use of VR in various company areas.
	Rapid Prototyping: Use VR to quickly and cost-effectively create and test ideas.
9. Integration with Other Technologies	Big Data and AI: Combine VR with artificial intelligence and data analytics to create personalized experiences.
	Internet of Things (IoT): Integrate connected devices to enrich interactions in the virtual environment.

Let me know if you need any adjustments!

CONCLUSION

FINAL CONSIDERATIONS

This study analyzed in detail the application of the metaverse in Industry 4.0, highlighting a multifaceted scenario where emerging technologies converge with traditional industrial practices. Real examples demonstrated the benefits and improvements obtained by adopting the metaverse in different businesses.

Based on an extensive literature review, the main enabling tools of Industry 4.0 were defined, using the metaverse attributes proposed by Weinberg and Gross (2023). The correlation table developed allowed a simple analysis of the maturity level of these tools, based on methodologies such as those of Schneider (2018) and Gokalp (2017). By applying this methodology to a real company, it was possible to identify critical points and propose a comprehensive improvement plan, evidenced by a radar chart. These results provide the basis for the development of future applications in the Industrial Metaverse.

EMERGING APPLICATION TRENDS IN THE INDUSTRIAL METAVERSE

The possibilities of the metaverse include the three-dimensional visualization of projects, with integration of real-time data captured by IoT sensors. Companies such as Airbus and Procter & Gamble demonstrate how simulation and adjustment in virtual

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environments result in savings of time and resources (AIRBUS, 2021; PROCTER & GAMBLE, 2020).

Another highlight is distributed collaboration, allowing teams in different locations to meet in virtual spaces, reducing travel costs and facilitating richer interactions than those provided by traditional videoconferencing. Companies such as Volkswagen use the metaverse for virtual workshops, increasing productivity and accelerating the development of innovative solutions (VOLKSWAGEN, 2022).

CHALLENGES AND ETHICAL CONSIDERATIONS

The implementation of the metaverse still presents significant challenges. The main ones include the high initial costs of investing in technological infrastructure, the need to train employees to operate in virtual environments, and the integration of legacy systems with new technological tools.

In addition, resistance to cultural change can be an obstacle that needs to be overcome through awareness campaigns and ongoing training. Issues related to data security also emerge as a critical point, requiring the development of robust cybersecurity solutions to protect sensitive information in virtual environments.

Therefore, we can say that the implementation of the metaverse faces technological and ethical challenges. The robust IT infrastructure required, including high-capacity servers and efficient networks, is a significant obstacle (Lee et al., 2024). Interoperability between systems and the lack of universal standards also complicate data integration, resulting in silos and operational inefficiencies (Yang et al., 2024).

In terms of security, the metaverse expands the attack surface, requiring measures such as data encryption, multifactor authentication, and continuous monitoring. Furthermore, it is crucial to ensure privacy and transparency in the collection and use of data, in compliance with regulations such as GDPR and LGPD (Kaspersky, 2022).

Overcoming these challenges requires investments in infrastructure, standardization, and team training. Collaborative initiatives between companies and organizations can establish a safer and more reliable environment, which is essential for the consolidation of the metaverse in Industry 4.0.

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FUTURE PROSPECTS

Based on the results obtained, the prospects for the use of the metaverse in Industry 4.0 are promising. Advances in immersive technologies, combined with improvements in connectivity and data processing, are expected to enable the expansion of metaverse applications in various industrial areas.

Furthermore, the integration of the metaverse with artificial intelligence and predictive analysis tools has the potential to further optimize processes, reduce costs, and increase competitiveness. The implementation of digital twins and real-time simulations will be a competitive differentiator, enabling companies to anticipate challenges and continuously innovate in a constantly evolving market..

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