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THE RELATIONSHIP BETWEEN IKUJIRO NONAKA'S KNOWLEDGE SPIRAL AND THE SIX INDUSTRY PRINCIPLES 4.0 IN THE CONTEXT OF DIGITAL TRANSFORMATION

A RELAÇÃO ENTRE A ESPIRAL DE CONHECIMENTOS DE IKUJIRO NONAKA E OS SEIS PRINCÍPIOS DA INDÚSTRIA 4.0 NO CONTEXTO DA TRANSFORMAÇÃO DIGITAL

LA RELACIÓN ENTRE LA ESPIRAL DEL CONOCIMIENTO DE IKUJIRO NONAKA Y LOS SEIS PRINCIPIOS DE LA INDUSTRIA 4.0 EN EL CONTEXTO DE LA TRANSFORMACIÓN DIGITAL

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ABSTRACT

Objective: The 4.0 industry is the current trend in automation and data exchange in organizations, there is no common, generic understanding in terms of evaluation, it is necessary to understand the main principles of Industry 4.0 and manufacturing processes for organizations.

Methodology: This research used inductive method, exploratory and descriptive research, and a bibliographic research was carried out, besides a qualitative research as field research. However, the systematic literature review methodology (SLR) of Tranfield et al. (2003) was used to ensure the replicability and transparency of the study review process.

Main results: The industrial phenomenon 4.0 that Schwab (2016) and Burke et al. (2017), called the Fourth Industrial Revolution, was guided by six design principles theorized by Hermann, Pentek and Otto (2015), considering the five dimensions of the knowledge spiral and the six principles of industry 4.0, which can help managers of technologies and organizational strategies in decision making.

Relevance/originality: With the advances in technology and the advances of the industrial revolutions, the profile of professionals and the relationship between employees and companies were changed, making it possible the degree of knowledge of managers on the subject and perception Industry 4.0.

Theoretical contributions: Ikujiro Nonaka's knowledge spiral has been an elementary theoretical basis for understanding the creation and flow of knowledge in a two-dimensional structure.

Management contributions: One of the criticisms is the nature of the knowledge (power, density and speed) that circulates in the organization. Another criticism in relation to its life cycle (creation, organization, formalization, sharing and application).

Keywords: Digital Transformation, Industry 4.0, Knowledge Management. Ikujiro Nonaka. Strategic System.

RESUMO

Objetivo do estudo: A indústria 4.0 é a tendência atual em automação e intercâmbio de dados nas organizações, mas é necessário entender os princípios principais da Indústria 4.0 e os processos de fabricação das organizações.

Metodologia: Esta pesquisa utilizou método indutivo, pesquisa exploratória e descritiva, e foi realizada uma pesquisa bibliográfica, além de uma pesquisa qualitativa como pesquisa de campo. Entretanto, a metodologia de revisão sistemática da literatura (SLR) de Tranfield et al. (2003) foi utilizada para garantir a replicabilidade e transparência do processo de revisão do estudo.

Principais resultados: O fenômeno industrial 4.0 que Schwab (2016) e Burke et al. (2017), denominado Quarta Revolução Industrial, foi orientado por seis princípios de projeto teorizados por Hermann, Pentek e Otto (2015), considerando as cinco dimensões da espiral do conhecimento e os seis princípios da indústria 4.0, que podem ajudar os gerentes de tecnologias e estratégias organizacionais na tomada de decisões.

Relevância/originalidade: Com os avanços da tecnologia e os avanços das revoluções industriais, o perfil dos profissionais e o relacionamento entre funcionários e empresas foram alterados, tornando possível a percepção do que é a Indústria 4.0.

Contribuições teóricas: A espiral de conhecimento de Ikujiro Nonaka tem sido uma base teórica elementar para compreender a criação e o fluxo de conhecimento em uma estrutura bidimensional.

Contribuições para a gestão: Outra crítica é em relação a seu ciclo de vida (criação, organização, formalização, compartilhamento e aplicação).

Palavras-chave: Transformação Digital, Indústria 4.0, Gestão do Conhecimento. Ikujiro Nonaka. Sistema estratégico.

RESUMEN

Objetivo del estúdio: La industria 4.0 es tendencia actual en materia de automatización e intercambio de datos en las organizaciones, pero es necesario entender los principios principales de la Industria 4.0 y los procesos de las organizaciones.

Metodología/enfoque: En esta investigación se utilizó el método inductivo, la investigación exploratoria y descriptiva, y se realizó una investigación bibliográfica, además de una investigación cualitativa como investigación de campo. Sin embargo, se utilizó la metodología de revisión sistemática de la literatura (SLR) de Tranfield et al. (2003) para garantizar la replicabilidad y la transparencia del proceso de revisión del estudio.

Principales resultados: El fenómeno industrial 4.0 que Schwab (2016) y Burke et al. (2017), denominaron Cuarta Revolución Industrial, se guió por seis principios de diseño teorizados por Hermann, Pentek y Otto (2015), considerando las cinco dimensiones de la espiral del conocimiento y los seis principios de la industria 4.0, que puede ayudar los gestores de estrategias organizacionales en la decisiones.

Relevancia/originalidade: Con los avances de la tecnología y los avances de las revoluciones industriales, el perfil de los profesionales y la relación entre los empleados y las empresas se modificaron, permitiendo destacar la percepción de lo que es la Industria 4.0.

Aportes teóricos: La espiral del conocimiento de Ikujiro Nonaka ha sido una base teórica elemental para entender la creación y el flujo del conocimiento en una estructura bidimensional.

Contribuciones a la gestión: Otra de las críticas se refiere a su ciclo de vida (creación, organización, formalización, puesta en común y aplicación).

Palabras clave: Transformación digital, Industria 4.0, Gestión del conocimiento. Ikujiro Nonaka. Sistema Estratégico.

1. INTRODUCTION

The phenomenon of digitalization in industrial operations is profoundly changing the modes of production. The use of intelligent data in the productive processes has inaugurated a new period in the administration of production, as Santos et. al. (2018) pointed out. Yet, the wave of technological digitization in industry 4.0 has caused a ripple effect on the entire supply chain as analyzed by Ivanov et. al. (2019).

The advent of Industry 4.0, made possible by artificial intelligence, cloud computing and the internet of things, has thus brought about profound changes in organizational operations by changing traditional production models for a digital form in digital networks, which Schwab (2016) and Burke et. al. (2017) called the Fourth Industrial Revolution.

In this context, technological innovations are challenging pre-existing productive structures, bringing the promise of an exponential increase in productivity and more capillarity to global production platforms. Organizational management in this technological environment has demanded new research that contemplates the processes of digitization and knowledge, as Muller et. al. did (2020) by relating the constructs of absorptive capacity with the innovation strategy and business model design in the context of industry 4.0.

This digitization that emerges in a diffuse way interconnecting virtually individuals, machines, groups and organizations, has been modeled on technology design concepts such as interoperability, virtualization, decentralization, Real-Time Production, Service Orientation and modularization, which to such terms Hermann, Pentek and Otto (2015) identified as the six principles of Industry 4.0.

In this new digital scenario, organizations need to review the knowledge creation process at the moment they integrate new technological artifacts into their operations. Nonaka et. al. (2006) conceptualize knowledge creation as a continuous process of information and past learning updated in new contexts through the interaction and sharing of tacit and explicit knowledge. In this relationship of tacit and explicit knowledge is that the cycle ('SECI') Socialization, Externalization, Combination and Internalization, called Nonaka's Spiral of Knowledge, emerges.

According to the SECI model, since knowledge is accumu-lated in each step, its conversion process is not cyclic but it is rather spiral, called knowledge spiral, because the knowledge is accumulated in each step. Knowledge is always im-proved upon, and acquired knowledge is added. The process of generating knowledge in a spiral is infinite. In the creation spiral of knowledge, the interaction between tacit and ex-plicit knowledge is amplified by four conversion modes. The spiral increases in scale as higher ontological levels are at-tained (Nonaka et Takeuchi, 1997; Nonaka et Toyama, 2003). Knowledge that is created by the SECI process can trigger a new spiral of knowledge creation, moving through interac-tion communities, which transcend departmental and orga-nizational boundaries, expanding horizontally and vertically. This knowledge can assist organizational departments in the innovation process (Nonaka et Toyama, 2003; Nowacki et Bachnik, 2016).

Aiming to contribute in the management field, this article takes the knowledge spiral model as the focus of analysis and application in the Industry 4.0 environment, considering its capacity to operate the structure of the six principles of Industry 4.0 oriented to digital transformation. In other words, the question is: *how can Ikujiro Nonaka's Spiral of Knowledge contribute to the process of digital transformation with reference to the six principles of Industry 4.0?*

Thus, in a first moment, the context of the subject of the essay will be presented with its problematic and its objectives. Then, a theoretical foundation will be presented that provides a basis for the subject matter. In the third stage, the aim is to discuss the relationships and convergent points found in the literature and presenting a diagnostic framework for the flow of knowledge within the organization. Finally, in the final considerations, comments will be developed that enable the direction of future research in the areas of technology management and industry 4.0.

2. THEORETICAL ASSAY CONTEXT

The productive sensorization through IoT (internet of things), IoS (internet of service) and Radio Frequency Identification (RFID) technologies is enabling the processing of huge volumes of data and information along the productive chains. Roblek et. al. (2016) observe that the present digital revolution is transforming the industry towards the modernization of information systems and industrial planning; automating systems in the data acquisition of production lines and machines; and interconnecting manufacturing sites optimizing supply chains. The data that in the classic knowledge model were acquired on the intranet are now saved in clouds, collected directly from things and customers in real time, and shared on virtual platforms.

The authors Santos et. al. (2018) schematically presented the industrial transformation in both their technological platform and data use mode, fig.1. Four industrial revolutions can be counted from the steam machine. The productive processes were transformed from machine operations to the intensive use of data.

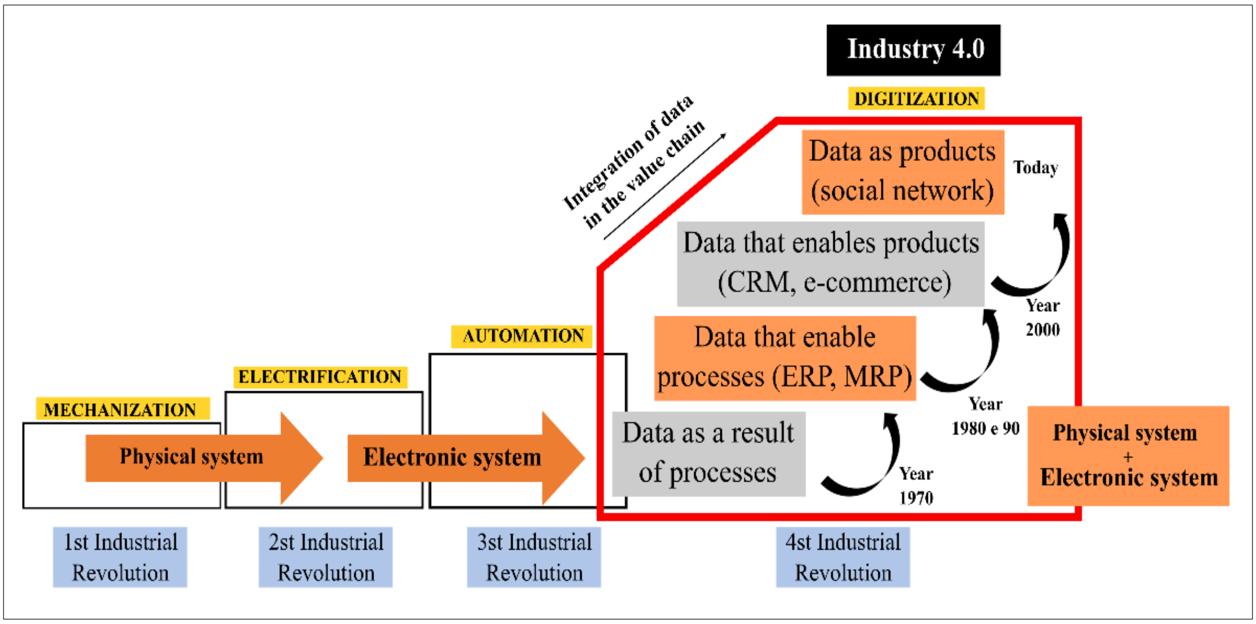

Figure 1. The industrial revolutions and the use of data
Fonte: Santos et. al. (2019)

The mechanization phase (1st Industrial Revolution) brought driving force to the production, that is, the mechanisms that took over most of the tasks of the craftsmen were coupled to the English steam machine, bringing speed and volume to the production system (Nuvolari, 2004, Peters, 2016, Schwab, 2016, Santos et al., 2018). In the Second Industrial Revolution that took place on American soil there were multiple inventions between 1870 and 1914 (Peters, 2016; Schwab, 2016; Santos et al., 2019) having as main factor the electrification of the production lines. From 1960 on, the companies started to use electronics and Information Technology in their production systems, creating the phenomenon of industrial automation called Schwab (2016) as the Third Industrial Revolution, as stated by Peters (2016), Xu et al. (2018) and Santos et al. Finally, during 2011, an industrial model of integrated technologies that connect the physical to the virtual environment (Peters, 2016;

Schwab, 2016; Santos et al., 2018; Madsen, 2019) was communicated in Germany during the Hanover Fair.

It is important to highlight, however, that these revolutions have caused significant changes in the use of production data and knowledge management. Machlup (1962) described knowledge in two senses, a first category as finished knowledge, in the sense of saying that "I know that person". In the context of the industrial revolutions and in the operation of data, it can be highlighted that if in the first and second industrial revolution the required knowledge focused mainly on machine adjustments and standardization of production systems, in the third revolution a knowledge of production quality and market research was demanded. In other words, the nature of the data in the third and fourth industrial revolution does not come only from the production processes, but also from the market, being therefore guides in decision-making.

Knowledge management in the third and fourth industrial revolution focuses on capturing, decoding and sharing information, developing and transferring knowledge to the operational practices of corporations (Roblek et. al., 2016; Bordeleau et al., 2019). Thus, it is necessary to consider the knowledge that emerges from the internal socialization of organizations, since technological advances, globalization of production processes and the emergence of new communication and information technologies have been shaping the way of managing knowledge in organizations (North & Kumta, 2018). Thinking about this socialization of knowledge in the intraorganizational, Ikujiro Nonaka's studies stand out. He observed the social environment of the organization as individuals interacting and exchanging knowledge seeking to ensure the accuracy of their operations through integrated and computerized processes.

Nonaka and Toyama (2003) proposed from the relation of tacit and explicit knowledge a cycle of socialization, outsourcing, combination and internalization of organizational knowledge by individuals. Later, several authors proposed adjustments to this model in order to make organizational realities adaptable to allow knowledge management based on the Nonaka Spiral model. Thus, it is not too much to say that the 4.0 industry that has been consolidating over the years as a platform for the use of data as management resources, may offer new opportunities for scientific research in the field of knowledge theory. This research, whether in the use of external knowledge as Muller et. al. did (2020) who analyzed the process of acquisition, assimilation, transformation and exploitation of knowledge in the context of industry 4.0., or in the investigation of the creation of knowledge as proposed in this article, can offer managerial approaches in production processes.

It is also worth mentioning that the present study has a relationship not only with industry 4.0, but also with digital transformation. And the main contribution of this publication is a proposal of knowledge mapping model in the digitization environment of production processes.

3. THEORETICAL BACKGROUND

3.1 Digital Transformation

The digital transformation process is the change of the industry's technological platform from a linear model to a network architecture. The introduction of digital devices integrating operations vertically and horizontally has allowed the increase of data flow between operations (Zuehlke, 2010; Schrauf & Berttram, 2016; Burke et. al.,2017; Yao et al., 2017; Oztemel & Gursev, 2018). These data, which were only the result of manufacturing processes such as temperatures, speeds and vibrations, became process enableers deliberating on preferences, desires and needs of customers; operated in social networks, tracked by digital memories of products produced by intelligent platforms, (Kagermann et al., 2013; Brettel et al., 2014; Roblek et al., 2016; Yao et al., 2017).

Schrauf and Berttram (2016) observed that in this new production dynamics centered in the data flow there will be an incentive to collaborative networking, flexibility in customer service bringing speed and productive synchrony, improving the adaptability of processes. This modularized, autonomous and responsive network is breaking the traditional hierarchy of production in the instances of work, while it is fed by the various types of data networked along the value chain, as shown in Fig.2.

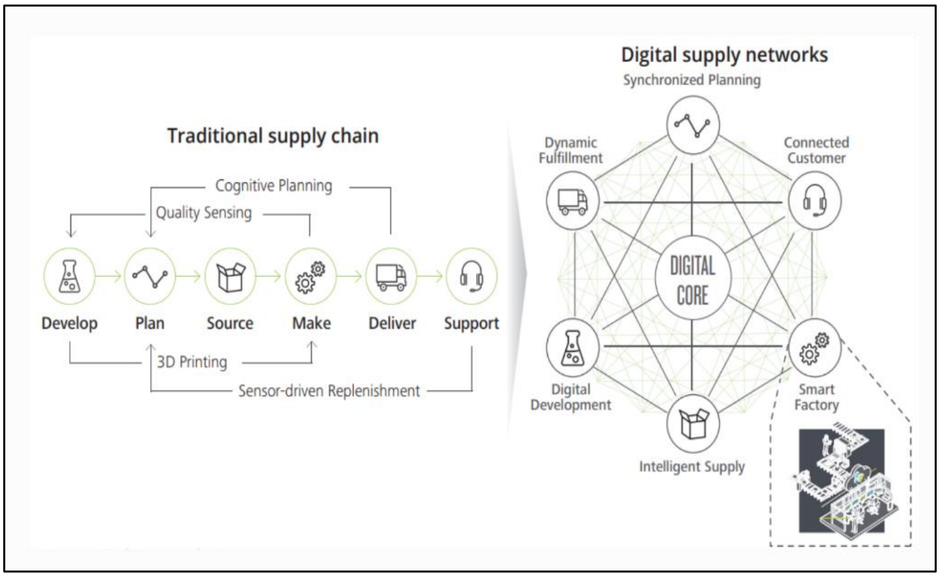

Figure 2. Change in Supply Chain Model.
Source: Burke *et. al.* (2017).

The main difference between the Traditional Supply Chain and the Digital Network model, demonstrated in Fig.2, focuses on the simultaneity of processes and the decentralized flow of data. In the traditional model, the integration of data happened in a limited way with non-automated or non-interoperable feedbacks concentrating mainly in closed production systems with little communication to the external market. In the networked model, the communication happens in a more open way, acting on Principles such as interoperability, virtualization, decentralization, real-time control, service orientation and modularization (Hermann et al., 2015; Ruppert et al., 2018; Ghobakhloo, 2018; Habib & Chimsom, 2019). The productivity of the Intelligent Factory is the result of a perfect performance of the vertical and horizontal integration that the intelligent network must offer. Aligned to market demand and connected to customer needs, resources become active elements in the construction of value oriented and reoriented by digital and intelligent means.

Lin, Ieromonachou and Sun (2016) point out that this transformation can be analyzed from the perspective of three propositions; the first one says that Smart Manufacturing focuses on the total performance of the supply chain and not only on a particular plant. The second proposition notes that the data covers not only plant operations, but all points in the supply chain. And thirdly, the supply chain model should focus on the knowledge and skills of professionals in order to balance technological advances and absorption of human resources, as clarified in the WEF report (2017, p.8): "*the Fourth Industrial revolution* *changes not only the way in which we produce and manage the supply chain, but also paves the way for the creation of new value chains*".

3.2 Smart Manufacturing

If the term Industry 4.0 has a Germanic origin, Smart Manufacturing was born in the United States as a set of manufacturing practices that from data operate the production, highlighted Mittal et. al. (2019). It is important to mention the study by Feng et. al. (2017) that analyzes the knowledge management in the Intelligent Manufacturing process (Smart Manufacturing) that conceived the advance of technological architecture as an integrating element of knowledge. In other words, the knowledge present in product design, planning, measurement and process control were combined observing the general context of data and information, breaking the knowledge into small units, and identifying the relevant units for application in intelligent manufacturing.

The authors Thoben, Wiesner and Wuest (2017) highlight the term Industry 4.0 or Intelligent Manufacturing (Smart Manufacturing), both aim at modeling the productive structures, facilitating harmony in the operation instances between man and machine. This manufacturing modeling has occurred through distributed manufacturing; autonomous machines; vertical and horizontal integrations; simulations in virtual environments; adoption of augmented realities; intelligent predictive maintenance; diffusion of mobile devices; cloud storage and real-time analysis of big data.

Intelligent Manufacturing is redirecting the way to manage the industry value chain. That operation that until then was focused on the production process only, is dedicating itself to data analysis and its use as a value component along the supply chain. Many industries struggled to build their manufacturing plants in places where labor was low cost and naturally, with little qualification, now, however, the automation associated with digitalization forces companies to seek highly qualified professionals. The authors Lin, Ieromonachou and Sun (2016, p.2, emphasis added) describe this transformation: "*We could regard smart manufacturing is a combination of knowledge and intelligence. […]The manufacturing process will not be labor-intensive anymore, but knowledge-intensive one*."

Feng et. al. (2017) emphasize that in this environment of transformation, Knowledge Management will gain relevance against Smart Manufacturing, unifying data and information; that once pulverized along the value chain and applied as a body of knowledge throughout the product life cycle from its planning, production, inspection and management of its supply chain; offering competitive advantage to the enterprise.

Smart Manufacturing, according to Kusiak (2018), can be presented schematically in two technological layers within the organization. One structure present in the productive equipment and another identified as Cybernetic, present in the corporate system. There is, therefore, a relationship between production equipment and Cybernetics of the company that happens through an interface. This interface connects the local intelligence, parked in the virtual memory of the equipment, to a Systemic Intelligence built in the virtual environment of the industrial network. This interaction, according to Kusiak (2018), was structured in the field of Computer Science, but Smart Manufacturing is using today in manufacturing technology and processes, in the development of intelligent materials, data processing and interpretation, Predictive Engineering, sustainability of materials, products and processes.

3.3 The Six Industry Principles 4.0 and the manufacturing processes

Faced with this digital environment Hermann, Pentek and Otto (2015) have identified six terms that allow thinking technological innovation in terms of management in the Fourth Industrial Revolution, they are: interoperability, virtualization, decentralization, Real Time Production, Service Orientation and modularization. These principles emerged in an attempt to define what would be Industry 4.0, since companies were remodeling their processes and Hermann, Pentek and Otto (2015) noted that in this new dynamic technological scenario of a disruptive nature it was important to identify some basic terms (design principles) to better understand the overall picture. In general, terms, the diffuse nature of the technologies identified by Kroll, Horvat and Jager (2018) can be at least understood by the absorption of these six principles.

The principle of Interoperability is the combination of company data, plant floor and product traceability integrating the organization vertically and horizontally for optimal connectivity (Hermann et al., 2015; Ghobakhloo, 2018; Ruppert et al., 2018; Habib & Chimsom, 2019). According to Cheng et. al. (2015) the interoperability of the various components in the computerized network of a given organization depends on the semantic degree that each element is constituted in the memento of its manufacture. Hermann et. al.

(2015) details that in Industry 4.0 CPS and human beings connect via IoT and IoS placing the standardization of communication as a key element.

According to Brecher et. al. (2014) it involves three stages: capturing the characteristics of the object to be virtualized, processing these virtualized variables with the digital network connected to a CPS system and thirdly producing items from the big Data of the general production network. Composed by semi-autonomous instances, the production control will be oriented to scalability based on self-adjustments, modeling and adaptations, operating from a simple regulation to a more intelligent operation (Kognition), seeking a balance between resources and complexity of tasks.

Hermann et al. (2015), Marques et. al. (2017) and Habib and Chimsom (2019) characterize decentralization as a system where there is not a central node through which all information passes, but several nodes making decisions individually in a synchronized manner through a collaboration mechanism between them. This collaboration network is formed by autonomous, heterogeneous and geographically distributed enterprises, ideal for SMEs. Odenbach et. al. (2017) reiterate that the Digital Age is marked by a tension between technologies that enhance decentralization and a tendency of large corporations to lead these innovations, leading to administrative centralization. Real-Time control can be developed from the combination of transparency and high volume of information, according to Spath et. al. (2013), Hermann et al. (2015), Ghobakhloo (2018). The time element, within the cost-quality-time triangle, is the key item within the production chain in order to provide control elements to the production system.

Service Orientation is the availability of data in an open system that allows flexibility and customization of products in order to bring efficiency in the process, i.e. the readiness of data increases the speed of response to market needs. Bauernhansl et. al. (2014) observe that in the three levels of the production process; traditional automation, in MES (Manufacturing Execution System) and ERP (Enterprise Resource Planning); each component needs to be service-oriented. That is, planning and execution processes occur simultaneously fed by a big data structured in the cloud. Service orientation involves "deshieraquization" through open standardization installed in a cloud structure.

Finally, Modularization, which facilitates the connection and disconnection of devices and technologies along the network bringing rapid responses to production seasonality’s. The process of modularization involves orienting the software in service and no longer the hardware, highlights Bauernhansl et. al. Within a framework where devices can interact with the various production levels without the limitations of rigid hierarchization. For example, within a logistics system the material flow needs to be operated within a logic of adaptability where mechanical and energetic devices must be equipped with control technologies that can circulate independently within the global system. This modularization will bring scalability, speed and adaptability to the seasonality of the global market.

Hermann et al. (2015) and Ghobakhloo (2018) observe that these terms can be understood as a systematization of the knowledge of the 4.0 Industry phenomenon, that after a grouping of publications organized by the authors, the six principles emerged as a representation that characterizes four important components for the 4.0 Industry: Cyberphysical System, Internet of Things, Internet of Services and Intelligent Factories. Table 1 shows the distribution of the principles among the main elements of Industry 4.0.

Table 1

The six principles distributed among the four main components of Industry 4.0

Description	Cyber-Physical Systems	Internet of Things	Internet of Services	Smart Factory
Interoperability	X	X	X	X
Virtualization	X	-	-	X
Decentralization	X	-	-	X
Real-Time Capability	-	-	-	X
Service Orientation	-	-	X	-

Fonte: Hermann et. al. (2015, our translation).

Still according to Hermann et al. (2015) and confirmed by Wang and Wang (2016), Ghobakhloo (2018), Ruppert et al. (2018) and Habib and Chimsom (2019) the development of the six principles in the four components of Industry 4.0 happens with the support of Machine-to-Machine (M2M) technologies, which is the intelligent communication between machines enabling the principle of interoperability. The relationship big data and cloud computing allows the development of the Internet Services, the Intelligent Factory virtualizing, decentralizing the entire operation that can be monitored in real time responding optimally to the seasonality of demand and production.

3.4 Spiral of Knowledge

The Spiral of Knowledge model, developed by Ikujiro Nonaka in 1991, was an important construction to understand the creation and flow of knowledge within organizations, as detailed by Nonaka (2007). Since its conception, the model has suffered substantial criticism regarding its structure and application, as can be seen in the works of Tsoukas (2002), Bratinau (2010) and Nissen (2014). However, other studies have confirmed the importance of the applicability of the model in the management of organizations, such as Goldman (2017); Mohajan (2017); and above all, Schniederjans et. al. (2020) who suggested as a future study the use of Nonaka's spiral in the process of knowledge creation with blockchain technology.

The Knowledge Spiral was based on the Japanese concept called "Ba", which means "place of sharing" according to Nonaka and Toyama (2003). Through a dialectic process involving tacit and explicit knowledge, the organization's knowledge is synthesized in a spiral path. Nonaka (1994) had already characterized these two dimensions of knowledge as the epistemological nature of theory, where tacit knowledge (internal to the individual) was in contrast to explicit knowledge (visualized by all).

The other dimension of Nonaka's spiral model is ontological, that is, it concerns the place where knowledge is generated, and can be in the mind, in the interaction of individuals, or even, in an organizational dimension where several departments exchange their knowledge among themselves.

Nonaka and Takeuchi (2008) divide this path in a spiral relating the epistemological dimensions with the ontological ones in four stages, socialization, Externalization, Combination and Internalization, as demonstrated in Fig. 3. As shown in the figure, the spiral is a result of forces that amplify from the center to the edges and that due to its synthetic nature is directed either to the individual or the interaction between individuals.

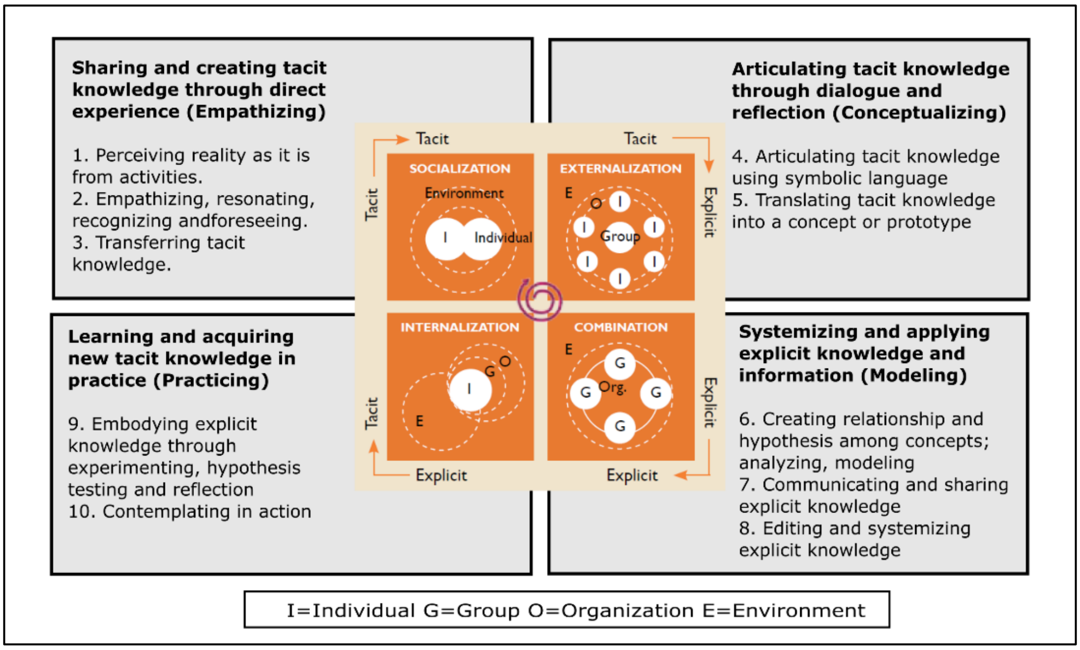

Figure 3. Spiral of Knowledge
Source: Nonaka and Takeuchi (2008).

The Socialization process is the stage where one individual's tacit knowledge is transmitted to another through observation, demonstration, and practice, directly sharing experiences, as Nonaka and Takeuchi (2008) stated. Outsourcing is the transformation of tacit knowledge into explicit, that is, personal, cognitive and technical knowledge is transformed is rationally externalized so as to be demonstrable in graphics, texts and reports, and that according to Nonaka and Takeuchi (2008) would be organizational knowledge.

In the Combination step the exchange of knowledge takes place between explicit-explicit, a collection of data and reports handled internally in departments and groups, now combine with other explicit knowledge that can be in the external or internal environment of the organization, leading to a corporate realignment, adjusting business strategies in the face of a new panorama identified, Nonaka and Toyama (2003). At this stage, the contradictions are solved by synthesizing the knowledge and applying it in the organization. This explicit knowledge once verbalized in the organization can be internalized by individuals in tacit format absorbing methods, practices and techniques in their individual operations.

So stated Nonaka and Takeuchi:

> "*In our vision, however, tacit knowledge and explicit knowledge are not entirely separate, but mutually complementary entities. They interact and exchange in the creative activities of human beings. Our dynamic model of knowledge creation is*

> *anchored in the critical assumption that human knowledge is created and expanded through the social interaction between tacit knowledge and explicit knowledge. We call this interaction "knowledge conversion*". (Nonaka & Takeuchi, 2008, p.59).

In fact, the knowledge created by individuals in a tacit way follows a disaggregated path through rationalization, that is, transforming itself into explicit, depriving itself of any cognitive and technical form linked to the subject or "owner of knowledge", as Hendriks (1999) called it. Goldaman (2017) recalls that Nonaka and Takeuchi's great achievement was to provoke a discussion about the real capacity of a company to create knowledge and that the construction of the spiral model was nothing more than a support to understand this process. Mohajan (2017) reaffirms this position that the theory of knowledge developed by Nonaka and Takeuchi did not have great depths, but redirected theoretical studies into the issue of organizational decision making. Philipson and Kjellström (2020) were more forceful in their observations suggesting that the transition from tactical knowledge to explicit knowledge is only possible using mediators who operate what they called "sketches".

Others like Tsoukas (2002), Bratinau (2010), and Nissen (2014) return to the concept of light mass and heavy mass in the conversion of knowledge by realizing that the transfer of knowledge is tacit-tacit or explicit-explicit would have rudimentary similarities with the laws of thermodynamics. That is, within the organization a tacit-tacit transformation the knowledge would be more viscous, because it would be linked to the experiences of individuals and their connection to corporate culture, and therefore the transmission would be longer and heavier demanding the capacity of absorption of the receiver, beyond the very ambiguous nature of the knowledge in progress. The explicit combination, on the other hand, would be the fastest, marked by few ambiguities, rationalized knowledge and a means of transmission with little subjectivity, therefore, the knowledge would be less viscous and with a high degree of standardization.

In order for Nonaka's Knowledge Spiral to be applicable to the internal operations of organizations, Nissen (2014) adapted the spiral to a penta dimensional model by adding the "Life Cycle", "Speed" and "Power" dimensions of knowledge, as shown in Fig. 5. The focus of the Nissen model is to demonstrate how the flow of knowledge takes place within organizations going from individuals (knowledge owners) to the organizational level that would later be retransmitted to collaborators named by Hendriks (1999) as "knowledge reconstructors".

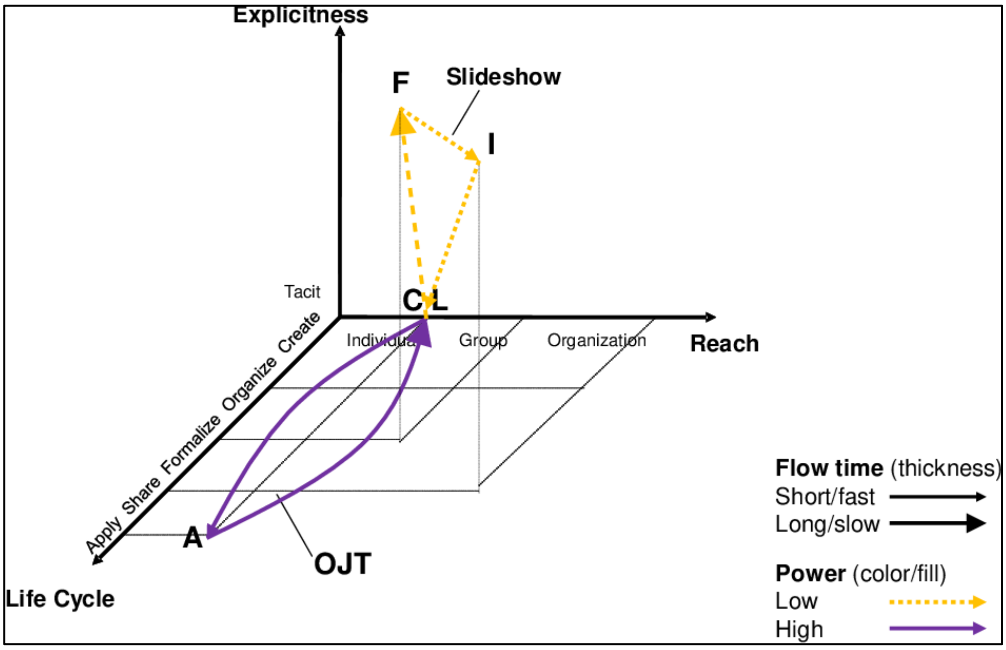

Figure 4. Knowledge Flow
Source: Nissen (2014)

Fig.4 shows the path from A to C the flow of knowledge happens at low speed, but with high power, this because it involves the sharing of experiences through observation, a stage called socialization. Then, from C to F, it happens the externalization of knowledge, the conversion of tacit knowledge into explicit knowledge, it happens at low speed and with low power. This loss of potentiality is due to the process of knowledge organization that requires the synthesization of the material body rationalizing it, eliminating personal cognitive and technical aspects, formulating general and presentable categories.

In the advance from F to I the formalization of knowledge within the organization with reports, manuals and checklists is already perceived. This is where the process of Combination with high speed happens, but as the knowledge is rationalized its power is low, that is, not very dense if compared with personal experiences. The "speed" dimension indicated by the thin and thick lines, and the "power" dimension represented by the dotted lines, reveal the complexity of knowledge circulation within companies.

From stage, I to L happens the internalization of knowledge by individuals. A knowledge that flows in fast speed, but in low power through trainings, symposiums and congresses. The individual has access to a knowledge framework, but in an organizational context, the knowledge is not presented as in the first stage of the cycle. This loss of power and gain of speed is what characterizes the tacit and explicit knowledge relationship. The contribution of Nissen (2014) offers a great opportunity for the process of digital transformation.

4. DISCUSSION

From the concepts and theories presented so far such as the process of digital transformation of factories, the emergence of smart manufacturing, the design Principles of industry 4.0 and the theories of intraorganizational knowledge flow, an integrated analysis of these four themes is proposed. Digital transformation is driving corporations towards data-flow-centric operations. The architecture of networks allows the expansion of the productive system across countries, promoting machine-to-machine communication placing corporations more and more dependent on the knowledge of professionals than on operational labor. This is the concept of smart manufacturing when productive systems tend to combine knowledge, intelligence, cybernetics and technological infrastructure.

In this context, the six Industry Principles 4.0 designs are guiding elements in the digital environment. The flow of knowledge that corporations are employing in their digitizing operations tends to be configured around these Principles. The theory of tacit and explicit knowledge worked by the Nonaka cycle, with regard to the relationship between individuals and organizations, allows a reflection on how knowledge can flow within organizations in an environment of digital transformation. The tacit knowledge that is present in the individual in cognitive and technical form, as demonstrated in the theoretical foundation can manifest itself in Industry 4.0 through the perception, experience, way of manipulation and interpretation of data that each professional has when handling disruptive technologies. In other words, technology managers and promoters of digital transformation must know how to manage this tacit dimension of knowledge in each 4.0 principle by observing the combination of these dimensions in the smart business environment.

The explicit knowledge contained in technical reports, business rules, semantic glossaries, product and process repositories and metrics constitute the streamlined body of knowledge in organizations, where many publications related to the fourth industrial revolution are even being propagated from Germany to China. In general, explicit knowledge tends to be virtualized, as it is the lightest categories of knowledge, although of low power as already discussed, offers speed and flow in the intraorganizational. In the context of digital transformation, explicit knowledge tends to substantiate the basis for managers' decision-making. In the context of smart technologies, this data fusion tends to occur in real time, interoperable, modular and decentralized.

Thus, the correlation between the principles of Industry 4.0 and the spiral of knowledge (the tacit- explicit dimensions, intraorganizational life cycle, the power of knowledge and its speed) goes through the analysis of each principle from the two categories of knowledge, namely: tacit and explicit. Table 2 outlines this analysis in subcategories to better understand the unfolding of the principles within organizations, especially enterprises that have technology as a strategic element.

Table 2

List of Industry Principles 4.0 and their respective tacit and explicit knowledge

Principles	**Tacit Knowledge**	**Explicit Knowledge**
Interoperability	It is present in the operational experience of the technologies that each professional has.	Formalized structures such as terminologies, glossaries and repositories.
Virtualization	The knowledge that each technician has about the nuances of the production activity of the products, also the set of perceptions that each collaborator has regarding the characteristics of the product.	Technical reports of each product, machine adjustment specifications applicable to each process and product, as well as machine setups and software configuration capable of automating production.
Decentralization	Perception of individuals facing a different scenario; reaction of professionals facing an unexpected problem; mode of decision making of each professional.	Pre-defined business rules; technical measurements of services, products and processes; information stored in the ERP system, analysis tools and identification of data and information. .
Real Time Control	Interpretation of the effect of metrics on production.	Product and process metrics; glossaries of service and product specifications.
Service Orientation	Selection of the main metrics and technologies applicable to each internal process of the company.	Semantic glossary of standardization of indicators, metrics and specifications applicable to programming language and programmable logic commands.
Modularization	Convenience of response to some seasonal market demand and decision making to continue or discontinue some modular device along the production chain.	Semantic glossary of programming language and programmable logic commands.

Source: the authors.

The table 2 in shows that the principles of interoperability, decentralization and modularization have their tacit dimension focused on the perceptions and experiences of individuals. Moreover, when it comes to explicit knowledge in this new digital environment, corporations need to devote themselves to language semantics terms facilitating the adaptability of various devices within the company's global network. In other words, although the presence of professionals with deep tacit knowledge in Information System is vital, the generation of knowledge in these three highlighted principles lacks congruence from other areas such as commercial and production management (Silva Junior, Santos & Santos, 2020). To standardize the technological language so that ERPs are constantly updated, production reports must be more complete, informing adjustments and maintenance in order to make the production information more accurate.

Likewise, virtualization and Service Orientation (SOA) require comprehensive technical reports that allow optimal synchronization between technological infrastructure, product processing, and cloud computing and big data. All of this powered by sensors and switching actuators along the production chain that make business more and more intelligence as data becomes smart. In fact, the explicit knowledge that according to Nonaka and Takeuchi (2008) is the one that flows in the organization is what allows administrative theories to ground new management techniques in the process of digital transformation. The technologies of Industry 4.0 carry the promise of improving the productivity of the plant, concluding that the phenomenon of digitization and digitalization can instrumentalist strategic transformations in corporations (Morais & Monteiro 2019).

The list presented in Fig.7 evokes the creation of a dynamic organizational knowledge and responsive to the seasonality of the technology, in terms of new features and devices; as well as a body of knowledge that is efficient in responding to the dynamics of new markets and needs, placing strategic agents able to capture these new trends similar to gatekeepers - which in the theory of knowledge absorption capacity of Cohen and Levinthal (1990) play the role of translators of the external scenario into companies. Digitization offers indications that the traditional structures of automation and management systems (ERPs) are moving towards a complete network integration.

Therefore, in terms of epistemological dimensions, scope, life cycle, power and speed of intra-organizational knowledge, the checkpoints of the in Fig.5 can be guiding elements for managers and researchers in the context of Industry 4.0, considering the six design principles. The following chart can be considered an original contribution of this article.

Description	Epistemological	Life Cycle					Reach			Flow Time		Power	
Interoperability	Tacit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
	Explicit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
Virtualization	Tacit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
	Explicit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
Decentralization	Tacit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
	Explicit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
Real-Time Capability	Tacit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
	Explicit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
Service Orientation	Tacit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
	Explicit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
Modularity	Tacit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
	Explicit	C	O	F	S	A	I	G	O	Slow	Fast	Low	High
C - Create; O - Organize; F - Formalize; S - Share; A - Apply; I - Individual; G - Group; O - Organization													

Figure 5. The six principles of Industry 4.0 and the five dimensions of knowledge
Source: the authors

The table in Fig.5 can be applied to the mapping of the knowledge present in the organization, according to their respective natures and stages of implementation, and to the diagnosis of the level of digital transformation of the enterprise in the context of Industry 4.0. The proposal of this chart involves the development of a tool capable of guiding the actions of managers and researchers of the 4.0 industry phenomenon. In terms of knowledge theory vocalized by Ikujiro Nonaka and his collaborators, the relation tacit and explicit knowledge can be conceived as a complementarity where the former has the possibility of evolving to the latter. In other words, the phenomenon of digitization or digitalization can contribute positively to the transformation of tacit knowledge present in individuals who operate technologies in production systems to an explicit knowledge. In addition, in this context, the picture in figure 5 can contribute to a diagnosis or categorization of this knowledge according to the principles of industry 4.0.

As, for example, interoperability developed in software or hardware from the tacit knowledge present in professionals can, in a second moment, evolve to a more precise standardized semantic language in order to offer a competitive advantage to the organization in the general market. If, therefore, there is a greater frequency of tacit knowledge in the field of interoperability, as well as a high rate of explicit knowledge in virtualization, the technology or strategy manager will have another map of internal diagnosis of production for decision-making (Silveira Gontijo, & Motta Alves, 2019). This evolution from tacit to explicit can happen in a natural way, when a technology becomes popular in market economies, or in a managed way when an organization is dedicated to making reports, opinions and monitoring metrics - digitizing the information that circulates in production processes.

The authors Bratinau (2010) and Nissen (2014) understand that the flow of knowledge depends on the right environment and on individuals prepared to receive this or that knowledge. The chart in figure 5 can contribute to the admission of employees to the firm to reinforce the degree of tacit knowledge in the production system. Alternatively, even, to invest in some level of the life cycle of a certain knowledge that needs to be aligned with the strategy of the organization. The main contribution of this article is the possibility of contributing to new management assumptions in technology management and strategic decision-making in the context of digital transformation and industry 4.0 (Sabeti, Hashemzadeh, Gelard, & Rabiei, 2020). In this way, the organization's employees need to be equipped with skills that allow them to disseminate this knowledge in the various departments, structuring an environment that seeks transparency, open and intuitive standardization.

5. FINAL CONSIDERATIONS

Therefore, in the context of the digital transformation of the 4.0 industry, observing the flow of knowledge within the organization is vital for the survival of corporations. An accurate diagnosis or a management map of the conditions of this intraorganizational knowledge can offer a competitive advantage in the market in general. This article is dedicated to theorizing the relationship between the six principles and the spiral model, considering Nonaka's spiral critics and remodeling, offering as a result a framework for conducting organizational diagnoses regarding the flow of knowledge in relation to Design Principles 4.0.

In this article, it was not possible to detail the five dimensions developed by Nissen (2014) which would bring more depth to the subject. However, this article broadens the scope of Nonaka's spiral model in knowledge management and corporate strategy construction. The tacit and explicit knowledge relationship offers only a starting point in the process of classifying the knowledge that circulates in the 4.0 Industry phenomenon, as already detailed, it is necessary to consider the fluidity of this knowledge within the organization (Cruzara, Sandri, Cherobim, & Frega, 2021).

For future studies, it would be important to deepen the classification of the industry 4.0 principles in terms of its density and power in the application over the organization's processes. Another study is necessary regarding the relationship between the five dimensions of the Nonaka spiral and its impact on management practices in companies in the process of digital transformation. In the context of the applicability of the diagnostic framework of the flow of knowledge, it would also be advisable to investigate adjustments and usability in the management of technologies or strategies in corporations.

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