Digital transformation: patents as a determinant proxy for Industry 4.0

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CRediT authorship contribution statement

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Abstract

Objective of the study: To analyze the indicators of patents filed between 2008 and 2022 in the process of digital transformation of industries in Brazil and Portugal, seeking to understand the changes brought about by the Fourth Industrial Revolution (4IR).

Methodology/approach: The study is descriptive and applied in nature, using documentary research and access to bibliographic databases and legal protection institutes in Brazil and Portugal, as well as Questel's Orbit Intelligence database.

Originality/Relevance: The study differs in that the specific technologies that make up the 4IR studied on a large scale in the fields of information systems are less available within management fields, and the study compares two developing countries in terms of patents.

Main results: The comparative analysis of patents reveals that Brazil and Portugal have participated, albeit unevenly, in the development of enabling technologies in the context of digital transformation. Despite the technological gaps, both countries have increased patent filings, but to a lesser extent than developed countries.

Theoretical/methodological contributions: The study contributes methodologically by applying comparative analysis to the literature on patents and Industry 4.0. In theoretical terms, it includes digital transformation in the joint analysis of patents and industrial structure.

Social/management contributions: The study proposes a diagnosis capable of reducing the gap between the creators and users of Industry 4.0 technologies, which will make it possible to overcome technological gaps, encouraging the adoption of new technologies and the development of associated skills, which can generate positive impacts on society, such as creating jobs and increasing the competitiveness of the countries involved, as well as industrial and innovation policies in both countries.

Keywords: digital transformation, patents, Industry 4.0, technological catching-up

Transformação digital: patentes como *proxy* determinante para a Indústria 4.0

Resumo

Objetivo do Estudo: Analisar os indicadores de patentes depositadas entre 2008 e 2022, no processo de transformação digital das indústrias do Brasil e de Portugal, buscando compreender as mudanças suscitadas pela Quarta Revolução Industrial (4IR).

Metodologia: O estudo tem natureza descritiva e aplicada, utilizando pesquisa documental e acesso a bases de dados bibliográficas e dos institutos de proteção legal do Brasil e de Portugal, além da base de dados Orbit Intelligence da Questel.

Originalidade/Relevância: A pesquisa se diferencia à medida em que as tecnologias específicas que compõem a 4IR são estudadas em larga escala nas áreas de sistemas de informação, estão menos disponíveis dentro dos campos de gestão, bem como por comparar dois países em desenvolvimento no que se refere às patentes.

Principais resultados: A análise comparativa de patentes revela que Brasil e Portugal participaram, ainda que de forma desigual no desenvolvimento das tecnologias habilitadoras no contexto da transformação digital. Apesar dos *gaps* tecnológicos, os dois países têm aumentado o depósito de patentes, mas em proporção menor que os países desenvolvidos.

Contribuições teóricas/metodológicas: O estudo contribui metodologicamente ao aplicar análise comparativa à literatura sobre patentes e indústria 4.0. Teoricamente, insere transformação digital na análise conjunta de patentes e estrutura industrial.

Contribuições sociais/de gestão: O estudo propõe um diagnóstico capaz de reduzir o fosso entre os criadores e utilizadores das tecnologias indústria 4.0 que permita ultrapassar os *gaps* tecnológicos, incentivando a adoção de novas tecnologias e o desenvolvimento de competências associadas, o que pode gerar impactos positivos na sociedade, como a criação de empregos e o aumento da competitividade dos países envolvidos, além de políticas industriais e de inovação nos dois países.

Palavras-chave: transformação digital, patentes, Indústria 4.0, catching-up tecnológico

Transformación digital: las patentes como proxy determinante de la industria 4.0

Resúmen

Objetivo del estudio: Analizar los indicadores de patentes registradas entre 2008 y 2022, en el proceso de transformación digital de las industrias en Brasil y Portugal, buscando comprender los cambios provocados por la Cuarta Revolución Industrial (4IR).

Metodología: El estudio es de carácter descriptivo y aplicado, utilizando la investigación documental y el acceso a bases de datos bibliográficas y a los institutos de protección jurídica de Brasil y Portugal, así como a la base de datos Orbit Intelligence de Questel.

Originalidad/Relevancia: La investigación se diferencia por el hecho de que las tecnologías específicas que componen las 4IR se estudian a gran escala en las áreas de sistemas de información, están menos disponibles dentro de los campos de gestión, así como por la comparación de dos países en desarrollo en términos de patentes.

Principales resultados: El análisis comparativo de patentes revela que Brasil y Portugal han participado, aunque de forma desigual, en el desarrollo de tecnologías habilitadoras en el contexto de la transformación digital. A pesar de las diferencias tecnológicas, ambos países han aumentado el número de solicitudes de patentes, pero en menor medida que los países desarrollados.

Aportaciones teórico-metodológicas: El estudio contribuye metodológicamente aplicando el análisis comparativo a la literatura sobre patentes e Industria 4.0. Teóricamente, incluye la transformación digital en el análisis conjunto de patentes y estructura industrial.

Contribuciones sociales/de gestión: El estudio propone un diagnóstico capaz de reducir la brecha entre los creadores y los usuarios de las tecnologías de la Industria 4.0, lo que permitirá superar las brechas tecnológicas, fomentando la adopción de nuevas tecnologías y el desarrollo de competencias asociadas, lo que puede generar impactos positivos en la sociedad, como la creación de empleo y el aumento de la competitividad en los países implicados, así como en las políticas industriales y de innovación de ambos países.

Palabras clave: transformación digital, patentes, Industria 4.0; puesta al día tecnológica

1 Introduction

Within market logic, the convergence of manufacturing technology and Industry 4.0 technologies means it is essential for companies to formulate innovation strategies to strengthen their technological capabilities. Digital transformation is increasingly altering industrial processes and procedures and changing the relative positions of the main actors in the value chain and intellectual property regimes. It is important to emphasize that Industry 4.0 is a concept related to the Fourth Industrial Revolution (4IR), which encompasses digital transformation, automation and data exchange in technologies (Zhong et al., 2019; Ardito et al., 2019; Schroeder et al., 2019).

Although patents are an indicator often underestimated by the market, they play a fundamental role in identifying technological progress in countries and allow for financial benefits to be gained through the sale or licensing of technology, in addition to giving their holders a competitive advantage in the field of knowledge. In any case, in the traditional axiom of patents, inventions in industry have historically been protected by the intellectual property law system (Kim & Lee, 2015; White & Piroozi, 2019).

According to the National Confederation of Industry (CNI, 2020), in Brazil, the number of patent applications related to Industry 4.0 has increased 11-fold over the last decade. In 2008, 462 patents of this type were registered, representing 5% of the total of 23,170 applications. In 2022, there were 2,068 applications, corresponding to 8% of the 27,139 applications for patents that year. In Portugal, according to the Patent Index (EPO, 2022), the number of patent applications registered with the European Patent Office (EPO) by Portuguese companies and inventors increased by 7.6% in 2022. In Portugal, computer technology stands out as the field with the most patent applications filed with the EPO in 2022. It is worth noting that medical and pharmaceutical technologies were in second and third place, making healthcare the industry with the highest number of patent applications in Portugal when included in the context of Industry 4.0. In the last ten years, patent applications in Portugal have tripled in fields such as digital communication, medical technology, pharmaceuticals and furniture/games. There has also been considerable growth in sectors such as "information technologies for management", "control (of machinery)" and "electrical machinery, devices, energy".

Despite their growing importance, there is a gap in studies that focus on the technological dimension of countries' competitiveness based on digital technologies and patents. Recent studies

(IMD, 2017; WEF, 2018) have assessed digital competitiveness, covering technological, macroeconomic, and institutional factors. This article aims to bridge this gap by developing a conceptual and empirical framework based on patent indicators. In this respect, the aim of this study is to analyze patent indicators in the digital transformation process of industries in Brazil and Portugal, seeking to understand the ongoing changes and the reflections raised by the Fourth Industrial Revolution (4IR). The choice of these countries is justified by the fact that they are in a phase of technological catching-up, despite regional differences (Brazil as a developing Latin American country, Portugal as a member of the European Union).

This study contributes, theoretically, methodologically and empirically, to the field of the interface between Industry 4.0 and patents. From a methodological viewpoint, it conducts a comparative analysis of the literature on the relationship between patents and technological conditions in the context of Industry 4.0. In theoretical terms, the analysis enables the integration of digital transformation into the joint analysis of patent indicators in the context of the transformation of the industrial structure. In empirical terms, the results indicate that performance regarding the patent indicator can be considered a factor of competitiveness for the industries of the countries in question.

2 The use of patents as a means of digital transformation

A wide range of studies (Acs et al., 2002; Chang et al., 2015; Chen & Guan, 2016; Bakker, 2017) has highlighted the value of patents as legally protected intangible assets that are essential for companies to maintain a competitive advantage, as they effectively indicate the performance of innovation, including innovations in products, processes and technology. Indeed, patents are recognized as containing over 90% of the technical information that exists in the world, with 80% of this technical information not published in any other form.

There have also been studies that relate patents to the technological profiles of an industry, based on the assumption that technological revolutions are protected by patents and that these reflect the technological specialization of a country. From this perspective, analyzing patents provides a better understanding of the stage of technological development and levels of technological cooperation in industry (Cecere et al., 2014; Abbas et al., 2014). Previous studies have also assessed the performance of industry through patent-related information (Okamuro & Nishimura, 2013; Mingji & Ping, 2014). Indeed, patentability is considered an indicator in

assessments of the degree of a country's technological development, according to the perspective of the economic mainstream. Several instruments have been proposed to gauge the degree of digital transformation in a country. Lee et al. (2017) demonstrated, through several patent-based indices, an increase in the proportion of scientific knowledge and its positive relationship with impacts on innovation, highlighting the consistency of measuring companies' R&D activity. Wollschlaeger et al. (2017) analyzed technological trends and the impact of the Internet of Things (IoT) on industrial patenting. Curran and Leker (2011) proposed three methods to identify industrial convergence, using scientific articles, patent analysis, and cooperation projects. Dechezleprêtre et al. (2017) found that a small number of global ICT companies are responsible for a large share of the patent applications related to Industry 4.0. Ciffolilli and Muscio (2018) highlighted the concentration of participation in Industry 4.0 in specific regions of Europe, while Eastern and Southern Europe have a limited and marginal share of the process.

When considering the extant literature, it is important to recognize that technological change is a complex phenomenon that is difficult to capture with a single indicator (Abbas et al., 2014; Kowalski & Michorowska, 2014). Nevertheless, patent statistics have been widely used to assess competitive positions in various technological domains, both at the firm and country levels (Kim & Lee, 2015; Dziallas & Blindt, 2019). It is important to emphasize that several empirical findings, as highlighted in the study by Weresa (2019), have suggested a significant positive relationship between different techniques and indicators used to analyze patent-based technological change. These techniques include patenting propensity (Pantano et al., 2018), modeling-based approaches (Choi & Song, 2018), patent citation (Van Raan, 2017), and patent-based indices that assess technological advantages, such as the patent h-index, patent asset index, and impact index (Montresor & Quatraro, 2017; Makhoba & Pouris, 2019).

3 Method

The present study follows a descriptive approach, seeking to observe, record and analyze the phenomena or technical systems related to patent analysis without closely examining the merits and reasons for its contents (Sampieri, Collado & Baptista, 2007). Regarding the nature of the research, a quantitative approach is used, employing numerical metrics that are classified and analyzed through statistical techniques (Bryman, 2011). In this respect, the study is of an applied nature and was conducted using bibliometric research methods and R statistical software. For the

data collection, the databases of the legal protection institutes of Brazil and Portugal were used, as well as the commercial database Orbit Intelligence, produced by Questel, which contains information and access to patents and applications from Q-Pat (European and US patents) and FILE PLUSPAT (from 107 patent jurisdictions).

In the patent study, keywords (strings) were selected using two methods: the frequency of terms in articles through bibliometric analysis in the Web of Science and Scopus databases and an initial search with the term "industry 4.0" in Orbit.

Using this approach, 399 articles published between 2008 and 2022 related to the theme were identified, including topics, titles, abstracts and keywords in the Web of Science and Scopus databases. However, following the removal of duplicate articles and due exclusions, the final result was 101 articles. Using R statistical software, the 6 most representative technologies were identified: additive manufacturing, artificial intelligence, robotics, internet of things, synthetic biology and cyber-physical systems, as shown in Figure 1.

For the empirical analysis, data on applications for patents in Brazil and Portugal between 2008 and 2022 were considered. The years 2023 and 2024 were excluded due to the 18-month patent secrecy period. The timeline under study includes changes that occurred on a global scale, including the 2009 global financial crisis, the progressive implementation of new technologies, digital transformation and the COVID-19 pandemic. For this purpose, a new classification of patents related to the 4IR provided by the EPO (2017) was used as the basis for the analysis.

The search strategy used to obtain patent data related to the 6 selected technologies was based on the combination of Boolean connectors on the Orbit platform. The data were analyzed using graphs that mapped the main inventors, countries where the patents were filed, the legal status of the technologies and their applications. The analysis included research on patent holders, the International Patent Classification (IPC) and patent families. Furthermore, specific cases were researched in both countries to identify the relationship between the enabling technologies of Industry 4.0. To summarize the related technologies, countries and applications, a matrix of technological applications was developed.

Figure 1

Research Model
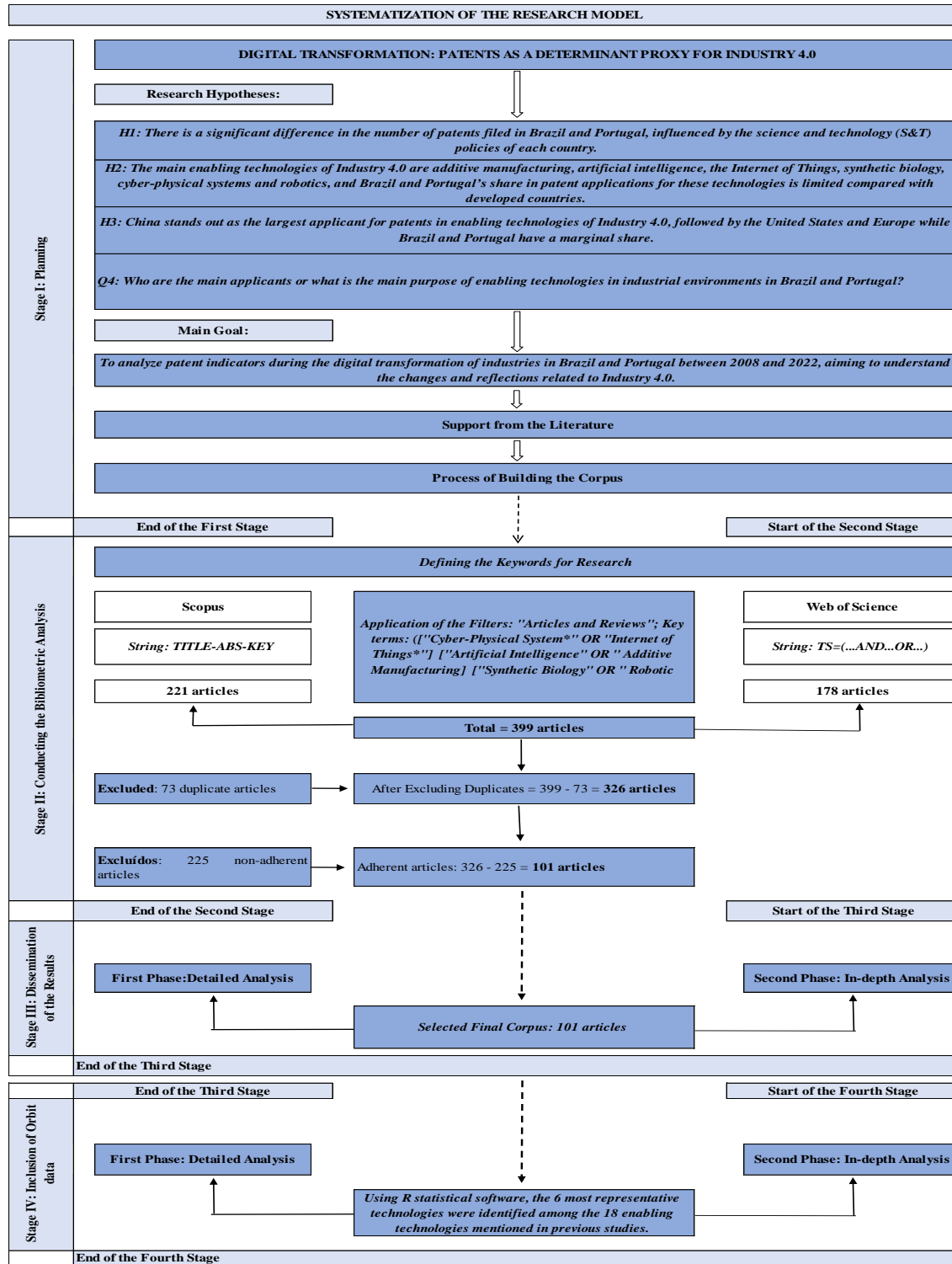
Source: The authors (2024).

Subsequently, a search was conducted in Orbit using the keywords shown in Table 1 with the respective Boolean operators and truncators, using the filters for World, China, EPO, Brazil and Portugal for the years 2008 to 2022.

Table 1

Keywords used

Keywords
Additive 1W manufactur*
Artificial W intelligence
(Artificial W intelligence) AND Industry
IIoT
Internet of things OR IoT
Cyber W physic*
Synthetic w biolog*
Robotic*

Source: The authors (2024)

In summary, the patent search was conducted in the Orbit database, and Industry 4.0 enabling technologies were selected based on criteria related to their identification as key technologies in 4IR and their adherence to the International Patent Classification (IPC). In all, 6 enabling technologies were identified for analysis, selected based on bibliometric search frequency and initial search using the terms of "disruptive technologies".

4 Results and Discussion

The results and discussions of this study will be presented in response to the research hypotheses that were developed to achieve the main research goal.

4.1 H1: Is there a significant difference in the number of patents filed in Brazil and Portugal, influenced by the science and technology (S&T) policies of each country?

In Brazil, most patent applications are filed with the National Institute of Industrial Property (INPI-Brazil), except in cases where applications are made directly to international institutions. In Portugal, applications can be filed with either the National Institute of Industrial Property (INPI-Portugal) or the European Patent Office (EPO), which grants patents at the

European level in accordance with the European Patent Agreement. In addition, it is possible to use the international patent filing system PCT (Patent Cooperation Treaty) to apply for protection in several countries.

Considering the assessment of the total number of patents filed in the two countries, in Brazil, most patents are applied for by non-residents, including multinational subsidiaries, while, in Portugal, most applications are filed by Portuguese residents. In 2022, most of the patent applications in Portugal (79.34%) were filed by local residents, with 312 via the European Patent Organization, 916 via the national route and 228 via the international route, totaling 1456 applications. In Brazil, the situation is different, as most applications (around 81%) were submitted by non-residents. For example, in 2013, of the 34,051 filings in Brazil, only 23.42% were by residents, while in 2022, this number increased to 24.75% of a total of 27,139 filings. From January to November 2022, of the 24,572 patent applications, there were the following participations: United States (31%), Brazil (18%), China (7%), Germany (6%), Switzerland and Japan (5%). Notably, most of these countries filed more than 72% of their applications through the PCT, except for Brazil, which used this system in only 3.2% of its cases (INPI, 2022).

According to data from the Patent Index (EPO, 2022), regarding global innovation indicators, Portugal has a more prominent position due to the higher number of patents per million inhabitants (30) and occupies the 27th position in the European ranking compared with Brazil (19.8). Moreover, there are differences in the origin of applicants: in Brazil, individual residents have the highest percentage of applications, while in Portugal, legal entities have the highest number of patent applications. In the Brazilian context, companies no longer lead patent deposits, with a significant increase in the participation of universities. In Portugal, applications via the European and international route are essentially creditable to the business sector, with holders residing in other countries. However, Feedzai leads the list of Portuguese applicants with the highest number of patent applications at the EPO, although most applications are from universities and research centers in Portugal, that is, six of the top ten applicants at the EPO are from this sector. The data also show that most patent applications in Portugal list the country itself as the first place of application. Some of the data found can be seen in Table 2.

Table 2

Data on patents filed and granted in Brazil and Portugal

Years	Patents Brazil (Filed with the INPI)		Patents Portugal (Filed with the INPI) – Domestic Route		Patents Portugal – European route (EPO)		Patents Portugal – International route	
	Applications by residents and non-residents in Brazil	Patents granted to residents and non-residents in Brazil	Applications by residents and non-residents in Portugal	Patents granted to residents and non-residents in Portugal	Applications by residents and non-residents in Portugal	Patents granted to residents and non-residents in Portugal	Applications by residents and non-residents in Portugal	Patents granted to residents in Portugal
2008	26,640	2,830	514	236	N/A	25	58	N/A
2009	25,890	3,164	723	213	N/A	24	201	N/A
2010	28,100	3,623	654	201	148	28	187	N/A
2011	31,880	3,813	772	219	136	26	144	N/A
2012	33,569	3,139	803	235	149	30	156	N/A
2013	34,050	3,325	867	228	215	26	246	N/A
2014	33,182	3,123	929	197	129	22	240	N/A
2015	33,043	3,895	1,178	186	152	46	211	N/A
2016	31,020	4,772	939	150	163	59	232	N/A
2017	28,667	6,247	846	159	155	68	180	N/A
2018	27,551	11,080	842	179	233	90	324	N/A
2019	28,318	13,742	965	202	290	110	254	N/A
2020	27228	21303	1124	248	251	70	249	N/A
2021	26522	27629	919	316	286	72	242	N/A
2022	27139	4033	916	216	312	29	228	N/A
Total	**442,799**	**115,718**	**12,991**	**3,185**	**2,619**	**725**	**3,152**	**N/A**

Source: Prepared by the authors based on data from the INPI, Portugal and Brazil (2024)

4.2 H2: The main enabling technologies of Industry 4.0 are additive manufacturing, artificial intelligence, the Internet of Things, synthetic biology, cyber-physical systems and robotics. Is Brazil and Portugal's share in patent applications for these technologies limited compared with developed countries?

Regarding the main enabling technologies of Industry 4.0, the data obtained were analyzed using the search for six key technologies, related to the industry, which identified the following result: Additive Manufacturing, Artificial Intelligence, Internet of Things, Synthetic Biology, Cyber-Physical Systems and Robotics. The patent search in Orbit revealed a total of 554,122 patents filed worldwide for these technologies, with 817 patents for Portugal (0.15% of the total) and 2,168 for Brazil (0.39% of the total) from 2008 to 2022. These patents represent only a small percentage of the total applications in the respective countries, indicating low involvement in these technologies compared with developed countries.

Table 3

Main enabling technologies of Industry 4.0

TECHNOLOGY	World	China	Portugal	Brazil	EPO
Additive 1W manufactur*	67,244	20,016	220	344	10,166
Artificial W intelligence	175,132	74,520	107	432	11,107
(Artificial W intelligence) AND Industry	6,379	2,688	3	10	192
IIoT	994	248	6	12	156
Internet of things OR IoT	198,161	79,419	173	530	9,929
Cyber W physic*	1,531	345	3	15	176
Synthetic w biolog*	2,152	778	5	21	308
Robotic*	102,529	23,694	300	804	12,670
TOTAL	**554,122**	**201,708**	**817**	**2,168**	**44,704**
% of TOTAL	100.00	36.40	0.15	0.39	8.07

Source: Questel's Orbit (2024)

Analyzing the global context, Brazil and Portugal are considered late-developing countries in relation to enabling technologies for Industry 4.0. While the United States stands out with a strong technological base in robotics and additive manufacturing, Brazil and Portugal are not recognized for these technologies. However, Portugal has increased its incidence of patent applications, despite structural limitations, especially through the EPO.

4.3 H3: China stands out as the largest applicant for patents in enabling technologies of Industry 4.0, followed by the United States and Europe. Do Brazil and Portugal have a marginal share?

Additive Manufacturing technology, which emphasizes the importance of R&D activities in associated fields, was researched for patent applications, revealing that China is the largest applicant, followed by the United States and the European Patent Office. In Brazil, the participation of subsidiaries of multinationals such as General Electric (GE) and Hewlett-Packard (HP) is significant, indicating the growth of research and development (R&D) activities and patents filed by these companies, which already occupy first place in the global ranking, as shown in Figure 2. In Portugal, as can be seen in Figure 3, the largest applicant is a Portuguese resident, but some applicants choose to file their priority applications in other offices, such as the EPO, due to more attractive markets. It was also possible to observe increasing interest in patent protection in China and Brazil from 2014 onwards, in keeping with the digital transformation of these

countries. However, despite the significant number of Chinese applications, only a small share of these is considered technologically relevant at the international level in the field of additive manufacturing.
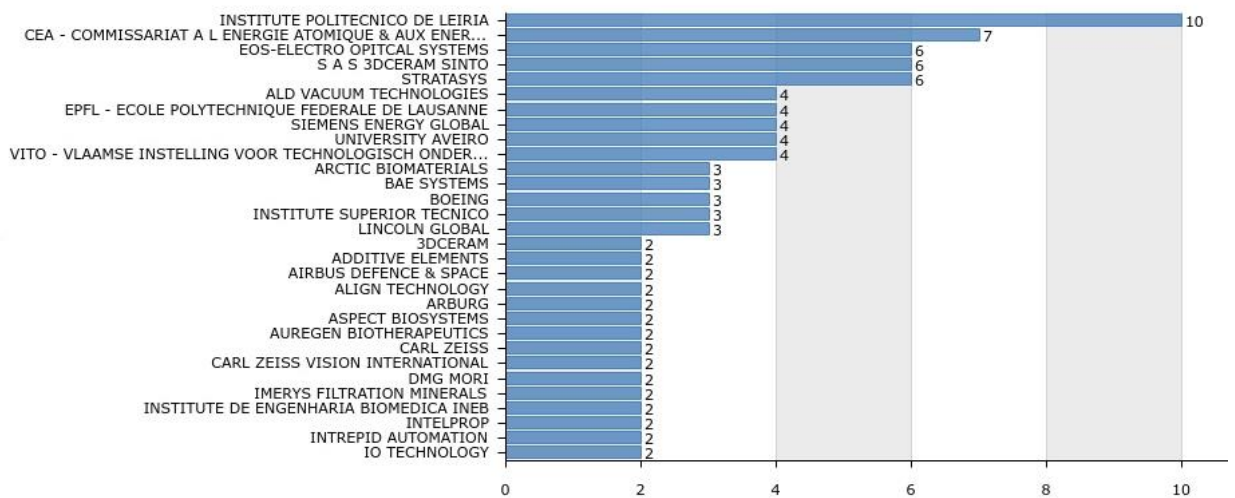
Figure 2

Applicants in Brazil – Additive Manufacturing
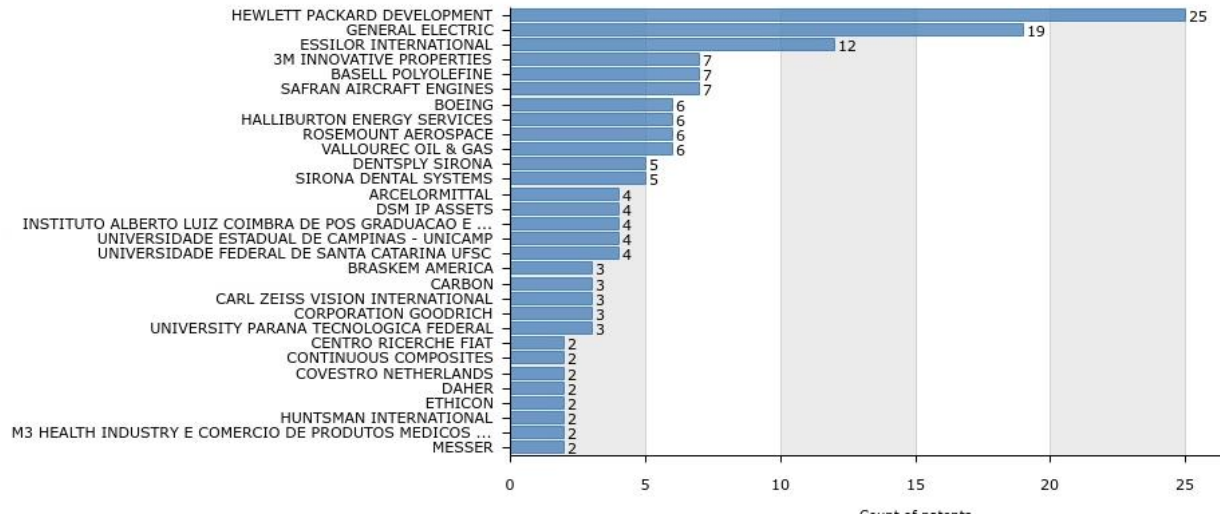
Source: Questel's Orbit (2024)

Figure 3

Applicants in Portugal – Additive Manufacturing

Source: Questel's Orbit (2024)

In the context of Internet of Things (IoT) technology, the data show that China has the highest number of patent applications, with 79,419, out of a total of 198,161. In comparison, Portugal registered 173 applications and Brazil registered 530 in this area. Of the 994 applications applied to the industry (IoT), the United States of America leads with 290 applications, while China was responsible for 248, Portugal registered 6 and Brazil 12. The leadership of Asian countries, especially China, in IoT-driven digitalization has been increasingly evident, challenging the United States as the leader in the sector, a trend reinforced by studies showing China's growth in this domain (Ardito, et al., 2018; Mehmood et al., 2016).

Data on Artificial Intelligence (AI) patents reveal that China is the country with most applications, totaling 74,520, out of a total of 175,132, while Portugal registered only 4 and Brazil 77 in this field. Companies are the largest filers of AI-related patents, but it is important to highlight that Chinese universities and public research entities play a major role in fields such as machine learning, deep learning and neuroscience. Of note is Tencent Technology Shenzhen, a Chinese technology company that owns WeChat, with more than 5,500 AI patent applications. As for applications over time, there was a significant increase beginning in 2017, as shown in Figure 4, reflecting the growth of Industry 4.0 and the increase in intellectual property in enabling technologies. In Brazil, there was an increase in AI patent filings after 2014, reaching a peak in 2020, with a slight decline in 2021 and 2022, unlike the global scenario, which continued to see sharp growth.

Figure 4

Years of Applications in Worldwide – Artificial Intelligence
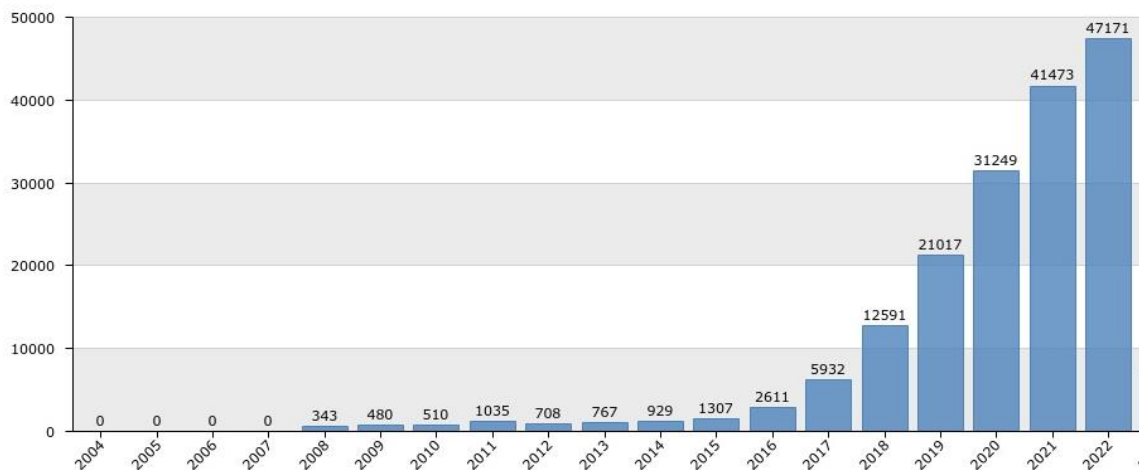
Source: Questel's Orbit (2024)

Regarding Cyber-Physical Systems (CPS) patents, out of a total of 1,531 applications filed from 2008 to 2022, 345 were filed by China, 3 by Portugal and 15 by Brazil. It should be noted that, of the number of patent applications filed worldwide, 521 were pending, a number slightly lower than the 641 patents granted. Among the 30 largest patent applicants in this technological field, companies such as Siemens and Qomplex stand out.

Regarding data on Industrial Robotics patents, China leads with 23,694 applications, with slightly more than the United States, which filed 23,678 applications, out of a total of 102,529. Next, the EPO (European Patent Office) registered 12,670 and Japan registered 7,749. The United States and China continue to lead innovation in industrial robotics, while Europe is becoming a major competitor in this field, with rapid growth in the number of patents since the 2000s. The presence of Chinese companies in patent applications is still limited, with medical companies from other countries being the main applicants. However, China is investing heavily in the field and plans to become one of the main producers of robots in the world.

4.4 H4: Who are the main applicants or what is the main purpose of enabling technologies in industrial environments in Brazil and Portugal?

The analysis of patents filed by Brazil and Portugal in the field of additive manufacturing revealed that the categories "other machines" and "metallurgical materials" are the main contributors concerning patents in this field. This highlights the significant development of these technological domains and the importance of strategic R&D planning for the future growth of the sector. Patent applications increased in the last three years in both countries. In Brazil, additive manufacturing applications in industrial environments are concentrated in assembly processes, metallurgy, tools and work instructions. In addition, auxiliary equipment and operations and chemical materials are also prominent. These applications represent 69% of AI patents, indicating great potential for innovation.

In the field of the Internet of Things (IoT), the 30 major patent applicants in Brazil and Portugal include companies such as Qualcomm and Ericsson, the main contributors regarding patents in this technological domain. The results also highlight Samsung Electronics, Sony and Philips, traditional leaders in home appliances, but show the expansion of ICT companies such as Google, Microsoft, IBM, Huawei, Cisco, Siemens and General Electric, which are developing

solutions for various sectors. The results contrast with studies by Mehmood et al. (2016) and Ardito et al. (2018), who identified the United States as the leader in this field.

Regarding the field of Artificial Intelligence (AI), in Brazil, the applications were mainly in the categories of computer technology, measurement and digital communication, with emphasis on digital information transmission and image data processing. In Portugal, the categories of computer technology, measurement and digital communication were also relevant with regard to AI patents.

In the field of Cyber-Physical Systems (CPS), the control and computer technology categories were the main contributors to patents in Brazil. In turn, in Robotics technology, the main technologies were related to medical technology and technology for manual implements, both in Brazil and in Portugal. In general, these are clearly common technologies for manufacturers of industrial robots and specific applications, such as radiation treatment, equipment for medical and sanitary cleaning, home cleaning or retention devices for semiconductor devices.

In short, despite the differences between the two countries, both in terms of the period analyzed and the sectors covered, both showed active and growing participation in the filing of patents, seeking recognition of their capacity for innovation through companies and scientific centers of excellence. Although previous ideas regarding the rigid division of countries into innovators and replicators are being abandoned, even countries with a less expressive technological past can enter the global innovation process and reap the rewards of this effort, as in the case of China. However, adequate preparation and guidance are required to achieve this goal.

5 Final Considerations

The results from the literature show an increase in patenting related to Industry 4.0 in Brazil and Portugal, mainly in networked devices and services (Benassi et. al., 2019). Younger technology companies are registering patents related to Industry 4.0, and there is a steady growth in the average number of patent applications over time.

Although patent applications for Industry 4.0 enabling technologies represent a small percentage of all filings, there has been an increase in Portugal and a subsequent increase in Brazil after years of decline. However, it is important to note that most applications are not filed by domestic residents, and this is not exclusive to Brazil. Furthermore, the number of patents granted in Brazil has increased despite the reduction in filings, indicating a more streamlined process for

analyzing and granting patents. These results show that both Brazil and Portugal are seeking to reduce the innovation gap with other countries and are taking advantage of the potential of Industry 4.0 to spur technological development.

The study revealed that innovation policies in Brazil and Portugal may have been affected by the crises (financial and COVID-19) faced during the period under study, together with the history and fragility of the manufacturing innovation systems in these countries. Despite the limitations and challenges, Brazil still has an industry of considerable size and potential, although it has undergone a process of deindustrialization, with a tendency to concentrate on low-productivity services. In turn, Portugal presents significant differences in its propensity to apply for patents, according to the sectors involved, with companies well positioned in international value chains.

Compared with previous research (Arundel, 2001; Cohen et al., 2000), it has been observed that countries with more developed industrial sectors, higher GDP per capita and larger populations file more patent applications related to Industry 4.0. However, the use of patents as a technological indicator has been questioned, as it may not fully reflect companies' innovation and technological appropriation. Furthermore, patents are more relevant for product innovations, while digital transformation advances mainly in the service sectors, meaning that it is important to consider other approaches and tools to measure the complex integration of sectors.

In the case of Brazil, the number of patents filed is below expectations considering its socioeconomic status, with multinational companies predominant in applications related to Industry 4.0. Conversely, in Portugal, local companies view intellectual property as a strategy for economic and social development, reflecting improvements in R&D indicators in recent years. Although both countries face structural challenges, Portugal has shown progress in innovation and has been classified as a strongly innovative country.

The social contributions of this study should be highlighted, emphasizing the narrowing of the technology gap, as the article proposes a diagnosis capable of reducing the distance between the creators and users of Industry 4.0 technologies, allowing existing technological gaps to be overcome. Furthermore, the guidance for industrial and innovation policies, as the study discusses existing development frameworks and proposes patenting trends, provides valuable aids for industrial and innovation policymakers in Brazil and Portugal, highlighting in the case of Brazil the New Industry Brazil Neo-Industrialization Plan (NIB-2024). Above all, strengthening their

innovation capabilities by identifying the fields in which Brazil and Portugal have increased their patent applications, the study suggests that these countries are seeking recognition for their innovation capacity, which can strengthen their economies and foster technological development. Finally, digital transformation is promoted, as the article helps to raise awareness of the importance of digital transformation in industry, encouraging the adoption of new technologies and the development of associated skills, which can positively impact society, creating jobs and greater competitiveness in the countries in question.

This study stands out because it addresses specific Industry 4.0 technologies, such as artificial intelligence, additive manufacturing, robotics, and the Internet of Things, with a focus on information systems. However, there are limitations to consider, such as the lack of analysis of the antecedents and effects of patent applications on other competitive dimensions of the countries, as well as the uncertainty and diversity of the technological trajectories of new technologies.

A suggestion for future research is to focus on comparative and longitudinal analyses of patent applications and patents granted, which would provide an opportunity to compare the trajectories of countries. As practical implications, the results highlight that the increase in 4IR patent applications is mainly explained by existing companies, rather than new companies, filing more 4IR patent applications over time. Furthermore, there is a general trend whereby companies tend to specialize in few technological fields.

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