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PATENT PROTECTION OF DIGITAL TWINS

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Abstract. The subject matter of this article is digital twins (DTs) and their protection by patents for inventions. It indicates the nature of digital twins and the application areas of the technology. The patent protection of digital twins is considered, and the advantages and disadvantages of the technology are presented. Examples of companies developing digital twin technologies are illustrated. The results of the patent study are analyzed. The patent applications filed and the patents granted for digital twins are identified in national and international aspects. All conclusions, as well as recommendations, are drawn on the applicants' activities in the field of study.

Keywords: digital twins; inventions; patent protection; intellectual property

JEL: A20, O30

Introduction

Scientific and technological advances are creating new waves of innovation in areas such as artificial intelligence, additive manufacturing, and digital twins (DTs). The dynamics of technological development worldwide and their protection through patents for inventions are of utmost importance for innovative enterprises. Patented digital twin inventions bring a number of advantages to their owners, licensors, investors, users, and humanity as a whole. Meanwhile, businesses face challenges in developing competitive, innovative products. The trend is increasing competition at both regional and global levels (Takov 2024). The pace and scale of globalization are unprecedented. Intellectual property and patents, in particular, are tools for technological progress, economic growth, and wealth creation.

Patents provide several benefits to their owners and a high return on the investment made in the development of technological developments such as digital twins. Through the use of patentable digital twin inventions, the right owner can make a significant profit if they manage to properly exercise the patent monopoly and take advantage of the benefits they have as the exclusive right owner of the invention.

In today's digital world, innovation is the driving force of the new economic reality (Stoyanova 2022). Innovations are one of the building blocks of technological progress, and hence of long-term economic growth and stable and sustainable development of the economy (Aleksandrov 2024). Through the innovative technology created, the goal is to attract the attention of users and hold it maximally and fully (Strijlev 2024). Digital twins are gaining widespread popularity and application in many areas of our lives such as aerospace, architecture, automotive, smart cities, retail, and many more. The creation of DTs serves to simulate real-world situations and their outcomes, which have positive sides as well as negative ones. According to ABI Research, by 2025, around 500 cities worldwide will use digital twins in city planning and management.

The key importance of digital twins is their ability to predict problems, improve the performance and efficiency of various systems, test the use of innovative products and improve asset management.

1. Essence of Digital Twins

The idea of digital twin technology was officially expressed in 1991 with the publication of the book "Mirror Worlds" by David Gelernter. However, Dr. Michael Greaves (then a professor at the University of Michigan) is credited with the first application of the digital twin concept in manufacturing in 2002 and for the formal announcement of the digital twin software concept. John Vickers of the National Aeronautics and Space Administration (NASA) introduced a new term – "digital twin" – In 2010[1].

However, the basic idea of using a digital twin as a means of studying a physical object is a concept that has been practiced since the 1960s. During this period, NASA used the concept of twins for space programming. They carry this out by creating physically duplicated systems on the ground level to match systems in space. An example of this occurred when NASA developed a digital double to assess and simulate conditions aboard "Apollo 13"[2].

Digital twins are virtual models of physical objects, systems, or processes that simulate their behavior and characteristics in real time. They are created by combining sensor data, simulations, and analytics to recreate the real behavior or state of existing assets or systems in real time. These models allow enterprises to monitor, analyze, and optimize production processes, infrastructure, and technologies in real time. Through digital twins, predictions can be performed on the efficiency of work processes, and potential problems can be identified for enterprises, contributing to informed decision-making and improved productivity.

There are different types of digital twins, such as a "digital twin of the product", which is a digital image of a real product. This type of DT can include products at different stages of the lifecycle, from initial conceptual design and engineering to full functionality – i.e., real-time data is obtained on the product as if it were

in operation. Other types are the so-called "data twin", a famous example being Google Maps. The application is a digital version of the earth's surface, which serves to connect real-time traffic data and aims to assist users in optimizing their journey. Other types of DTs include system twins, which model the interaction between physical and digital processes, including manufacturing processes, end-to-end supply chain management, store operations, and customer journeys. Infrastructure digital twins are used to represent physical infrastructure, such as a highway, a building, or even a stadium[3].

"Rolls-Royce", for example, use digital twins for their 'Intelligent Engine' program. The program creates DTs for every engine they produce. In this way, they can collect data on a number of parameters from on-board sensors. This allows them to monitor engine performance in real time during flights, predict maintenance needs and reduce downtime[4].

2. Areas of application of digital twins

The digital twins are being used by enterprises in several industries, the article will highlight some of the areas where they are involved and have gained wider use, such as:

2.1. Digital twins in manufacturing

In industry, a digital twin on a production line can monitor the performance of machines, alternating the real-time data on productivity and efficiency, and identifying potential interruptions. DTs are used to increase efficiency in manufacturing by creating a virtual copy of an industrial process. Manufacturers can evaluate data faster, analyze performance trends, and optimize operations.

Tesla is also using this technology to optimize production lines and to simulate new car models, helping to bring new technologies to the market quickly.

2.2. Digital twins in construction and infrastructure projects

A digital twin of a building or infrastructure could simulate the interaction of different systems, such as heating, ventilation, and air conditioning, allowing optimization of energy consumption.

The Virtual Singapore platform uses DTs to perfect a digital copy of the country. The platform serves as a comprehensive replica of Singapore that helps address urban planning challenges. With digital twins, they can simulate and test different solutions to improve the city[5].

2.3. Digital twins in the automotive industry

In the automotive industry, a car's digital twin can predict engine performance or vehicle safety.

Volvo creates virtual replicas to test and trial different materials and aerodynamics of new car designs. This way they can choose the ideal design that would improve performance and create models with low fuel consumption. Another example is the Ford company, which uses digital twins to develop its autonomous vehicles. Ford is testing its products in different driving scenarios and verifying the effectiveness of the self-driving

algorithms. In the virtual environment, they can safely test their product without the need for a physical prototype, helping to reduce the cost and time required for development[6].

2.4. Digital twins in healthcare

Digital twins find a variety of applications in the healthcare sector. These are used by modeling human organs or whole bodies to simulate treatment, to managing hospitals, such as optimizing patient and equipment flow.

The company, Twin Health, is creating a "total body digital twin" service that aims to help patients mitigate and reverse chronic metabolic diseases. Using company-provided hardware (i.e. sensors), routine blood tests, and self-entered data in a mobile application, a digital twin of the patient is created. Using artificial intelligence and proprietary models based on this digital twin, the application provides information about the patient's nutrition, physical activity, sleep metrics, and more[7].

2.5. Digital twins in agriculture

The digital twins also have wide applications in agriculture. They are used in the so-called "precision farming", to model crops, soil, and climate in order to obtain better yields. The technology is used as well in the optimization of agricultural machinery and the management of irrigation systems through simulations.

2.6. Digital twins in telecommunications

MYX is a Bulgarian startup founded in 2020 and dedicated to the creation and maintenance of digital twins. Using autonomous drone flights and specially designed algorithms, MYX works mainly in the telecom sector, collecting data on the critical infrastructure of telecom networks. This helps telecom service providers have real-time data on all their facilities and allows them to intervene in a timely manner[8].

2.7. Digital twins in retail

Implementing the digital twin technology in retail could improve a lot of customer service and store performance issues. A virtual store model could be used to test different product layouts and displays for the store to observe how they might affect customer flow and possibly purchase behavior. This helps retailers to discover the best approaches for increasing sales and improving the overall customer shopping experience.

2.8. Digital twins in the aerospace and aviation industry

The digital twins are primarily used to simulate space missions and vehicles and to train pilots and astronauts by simulating real-world training conditions. Virtual analogues of physical aircraft or aerospace systems are becoming indispensable tools for aviation and space research endeavors. As virtual analogues of physical aircraft or aerospace systems, digital twins have the potential to revolutionize design optimization, predictive maintenance, fuel efficiency, and safety.

3. Examples of companies creating digital twin technologies

Many businesses from different industries are creating and using digital twins to improve efficiency, reduce costs, and streamline operations. In this article, some of the leading international companies in the development of digital twin technology will be presented.

3.1. Siemens

Siemens offers a complete solution for digital twins in sectors such as manufacturing and energy. Siemens Digital Industries software enables the creation of digital twins for factories, machines, and entire production lines. This supports the optimization of design, production processes, and maintenance.

3.2. General Electric

GE Digital is a subsidiary of General Electric that offers a range of digital twin solutions for manufacturing, energy, and healthcare. GE's platform, called "Predix," allows companies to create and manage DTs of their products and systems and analyze data from those twins to improve productivity and efficiency[9].

3.3. Microsoft

Microsoft's Azure Digital Twins platform allows companies to create digital models of entire environments, such as buildings, factories, or cities. This platform allows enterprises to simulate and optimize operations, monitor systems, and improve decision-making.

3.4. Honeywell

Honeywell offers digital twin solutions for industries such as oil and gas, aerospace and manufacturing. These solutions enable real-time monitoring and analysis of equipment and processes. Honeywell's digital twin solution is also used as a virtual model to guide engineers with actionable information on machine performance and maintenance needs to optimize production[10].

3.5. Schneider Electric

Schneider Electric uses digital twins to improve energy management and optimize infrastructure. Their "EcoStruxure" platform enables the creation of digital twins for buildings and industrial systems, helping to improve sustainability and operational efficiency.

4. Advantages and disadvantages of digital twins

4.1. Advantages

Digital twin technology is one of the important technologies of Industry 4.0. Digital twins provide companies with virtual tools that allow them to view, explore, and evaluate physical assets, processes, and systems. With this capability, it is possible to get an accurate view of what is happening now as well as what will happen in the future. The advantages of digital twin applications are comprehensive, so only some of them will be discussed in the article:

Improved planning and design

The digital twins allow testing and simulation of different variants before they are implemented in real life. This reduces the risk of human error and serves to optimize product designs.

Reducing costs

Through simulation and prediction of potential problems, physical prototyping and testing needs are observed. This reduces the time for new developments and

implementation of new technologies.

Effective safety and training

Digital twin technology can be useful for safety simulations and employee training by replicating scenarios where employees can learn in a safe and controlled environment or become familiar with an object before physically traveling to their destination. Digital twins can help reduce workplace accidents by immediately reducing the need for frequent facility visits and promoting safety awareness by providing a model for employees to learn safety protocol and understand the ins and outs of the job[11].

Better sustainability

Digital twins help manage resources and minimize waste. They promote environmentally friendly solutions by simulating environmental impacts.

4.2. Disadvantages

Some of the main disadvantages of digital twins are as follows:

High initial investment

The implementation of the digital twins requires a significant initial investment, not only in terms of economic resources but also for infrastructure upgrades and staff training. Creating a complete digital twin system involves integrating IoT devices, advanced sensors, and data analytics platforms[12].

Complexity of implementation

The process of collecting data, processing it and integrating it into the simulation model is complicated. Improper integration could lead to inaccuracies in the simulations.

Dependence on data quality

Digital twins are only as accurate as the data they are fed on. If the data is incomplete, inaccurate or unreliable, the model could make wrong decisions.

Concern for data privacy and security

Digital twins inherently require the collection, storage, and processing of vast amounts of data. The increased flow of data increases the risk of cyber-attacks and data breaches, which can have serious implications for operational security and business integrity[13].

Maintenance of the technology

Digital twins require constant maintenance to stay up to date and synchronize with physical objects. This requires technical expertise and additional resources.

Technological dependence

The adoption of digital twins could create dependencies on specific technologies, service providers or platforms.

5. Patent protection of inventions for digital twins

There is no uniform definition of the invention, but in theory and practice, it is perceived as a technical solution to a problem in any field of social economy, which cumulatively must meet the criteria for patentability – novelty, inventive step, and

industrial applicability. Businesses creating digital twins must be sure that the subject matter they would like to obtain protection for is their own development and not taken from a foreign research result that has obtained patent protection in the territory where they will use it.

Before proceeding with the patenting procedure, enterprises should be aware of the subject matter that is excluded from protection under the Patent Law of the relevant country, such as discoveries, scientific theories, mathematical methods, results of artistic creation, representations of information, plans, rules, and methods for intellectual activity, for games or for business activity and computer programs. Businesses should be advised that not all intellectual products that are considered inventions can be protected through a patent. Under the Bulgarian Law on Patents and Registration of Utility Models, patents are not granted for inventions the commercial exploitation of which would violate public policy and good morals, methods of modifying the genetic identity of animals where there is a risk of causing suffering to them without any substantial medical benefit to humans or animals, and to animals obtained by such methods, methods of treating humans or animals by therapy or by surgery, and methods of diagnosis administered to humans or animals, except for products, in particular substances.

Patent applications for inventions that have successfully passed the patenting procedure before the Patent Office of the Republic of Bulgaria are granted a protected document called a patent. A patent for an invention may also be granted for methods, processes, technologies, chemical compounds, and biotechnological inventions. Once the patent is granted, the patentee obtains exclusive rights to the patentable invention, which includes the right to use the invention (manufacture, trade, offer for sale, etc.), the right of disposition (most often through licensing) and a prohibition on others using the invention without the patentee's consent. The recognition of the rights of patent owners over their developments reflects the significance of innovation for the competitiveness of any enterprise (at microeconomic level) and for economic growth in general (at macroeconomic level) (Krushkov 2024). Proper management of IP rights has a positive impact on the competitiveness of the companies (Markova, Pacheva 2022).

The patent is one of the main instruments for protecting the results of the digital twins' technologies. The patent has a territorial and temporal effect and is valid for the country whose Patent Office has granted it. The term of protection of the invention is twenty years from the date of filing of the patent application, and maintenance fees are payable annually until the expiry of the above period.

The patenting of technological developments for digital twins must be the result of careful and well-founded decisions, especially when companies intend to obtain protection not only at the national but also at the international level. Companies should now balance the needs of people, the planet, and profit (Todorova 2024). Patents should be beneficial to industry and society, as well as have a stimulating

effect on other business entities. Although inventions give a competitive advantage to the right owner, not all of them give an economic advantage to the patent owner – only those that the market has a real need for or would have a need for in a few years. The enterprises must analyze the external environment, including economic, social, political, and technological factors that may impact their competitiveness. This analysis helps understand market trends and identify opportunities and threats (Tsankova 2024). As regards the commercialization of intellectual property, the issue of competitiveness is also a key issue in satisfying the drive for high financial performance (Papagalska 2024).

6. Patent research methodology for digital twins

In the present article patent research will be conducted for patent applications and patents granted for inventions according to the methodology for conducting patent studies set by Prof. B. Borisov in "Methodology for patent research", Sofia, UNWE, 1999.

Determining the parameters of the patent research

– Purpose of the patent research

The purpose of the present patent research is to identify the patent applications filed and patents granted for digital twin inventions internationally.

– Subject of the patent research

The subject matter of the patent research is patent applications and granted patents for digital twin inventions filed with the Bulgarian Patent Office (BPO), the European Patent Office (EPO), the World Intellectual Property Organization (WIPO), the Chinese Patent Office, the United States Patent Office (USPTO) and the South Korean Patent Office.

– Countries to be surveyed

The territories covered by the patent research are Bulgaria, China, the USA, South Korea, international PCT applications for inventions filed with the WIPO, and European patent applications filed with the European Patent Office. The scope of the patent research has been extended beyond the territory of Bulgaria in view of the small number of applications filed by Bulgarian applicants under the national procedure before the Bulgarian Patent Office.

– Depth of the patent research

The patent research covers the period from 01 January 2015 to 01 January 2025, or a total of 10 years.

– Information sources

The following online databases were used to conduct the patent study:

– The online database of the Patent Office of the Republic of Bulgaria – www.bpo.bg;

– Lens online database (www.lens.org) – this database provides access to more than 160 million patent documents in over 95 jurisdictions.

In this article, only filed patent applications and granted patents for digital twins that are publicly available in online patent databases are considered.

– *Classification of the subject of patent research*

The results analyzed for patent applications filed and patents granted for digital twins cover a variety of technological developments that do not fall under the same section of the International Patent Classification (IPC). Thus, this research will not focus on a specific section of the IPC.

7. Results from the performed patent research and analysis of the information

Due to the fact that the digital twin technology is relatively new and has gained popularity and significance in recent years, patent research has been realized for the past 10 years. The patent research covers the patent applications filed and patents granted for digital twins for the period from 01 January 2015 to 01 January 2025.

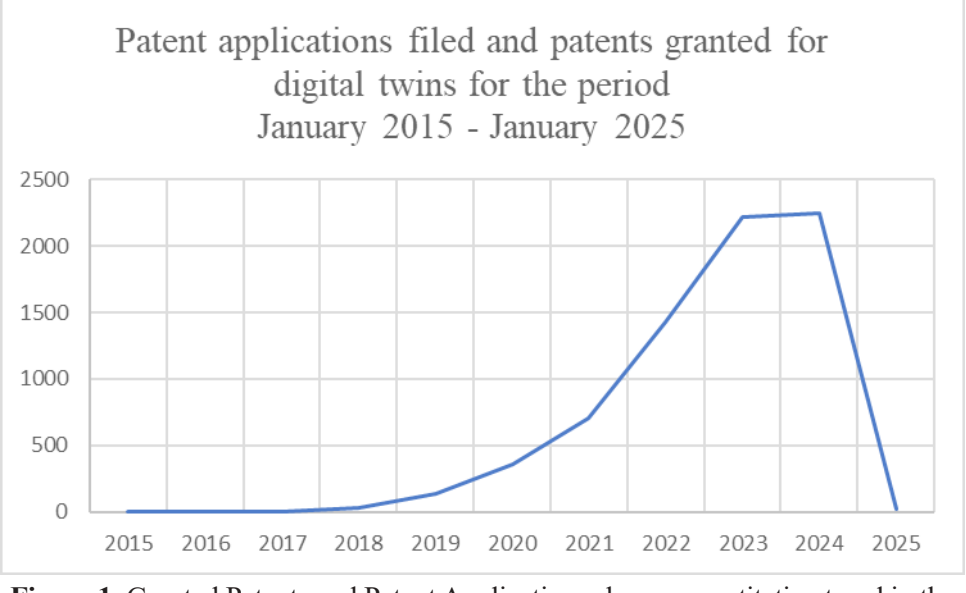

Figure 1. Granted Patents and Patent Applications show a quantitative trend in the subject of digital twins over the years

Source: Calculations based on the results of completed patent research in online databases – www.lens.org

No results were found for the period from 2015 to 2017, and 29 results in 2018. For 2019, the number of patent applications filed, and patents granted is 136, and in 2020, the number is 380. In the following years, there was an active increase in application activity; namely, 752 results were found for 2021, 1531 for 2022, and

2363 for 2023. The application activity reached its peak in 2024 with 2433 results found. At the beginning of 2025, 17 results were found.

The ratio between patent applications filed and patents granted for digital twins for the same period is shown in Figure 2.

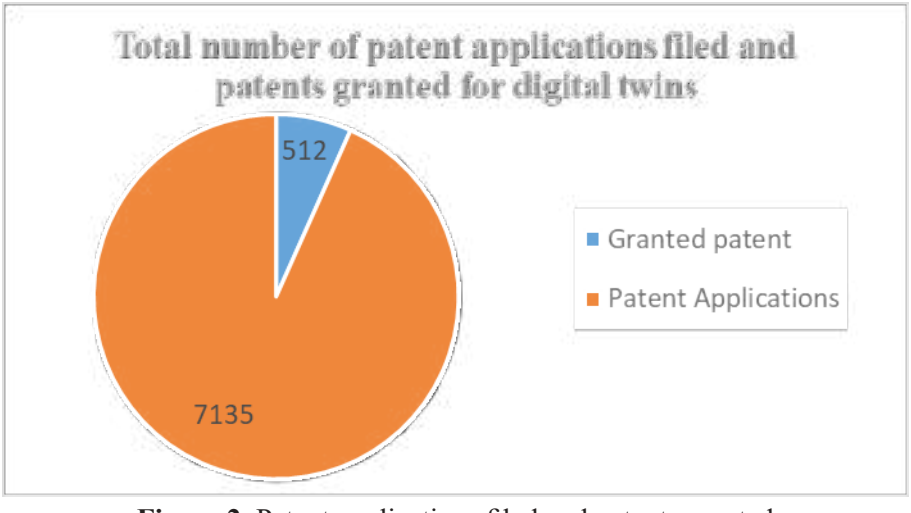

Figure 2. Patent applications filed and patents granted between January 2015 and January 2025
Source: According to online databases – www.lens.org

Considering the results of the table below, China has the highest number of patent applications and patents granted in the field of digital twins with 5476 results found. Second to China in the ranking is the USA with a total of 838 patent applications and patents granted. In third place is South Korea with 591 results, followed by WIPO with 366 international PCT applications filed, and in fifth place is the European Patent Office with a total of 223 patent applications filed and patents granted. Only one published result was found for the territory of Bulgaria. The patent application No. 113972, filed with the Bulgarian Patent Office, is entitled "Method of implementing a digital information-practical medical platform with a digital twin of a human individual," and it is still at the stage of "substantive examination."

The reason for the single result is both the extremely low patent application activity in the digital twin field and the fact that some of the patent applications have been filed recently and have not yet been published in the available patent databases.

Table 1. Total number of patent applications and granted patents by Country / Patent Office

Country / Patent Office	Total number of patent applications and patents granted
China	5476
USA	828
South Korea	591
WIPO	366
European Patent Office (EPO)	223
Bulgaria	1

Source: According to data of the online databases – www.lens.org, www.bpo.bg

Figure 3 below shows the applicants with the highest number of patent applications filed and patents granted for digital twins. According to the table results, the companies with the highest filing activity are Siemens Ag and IBM.

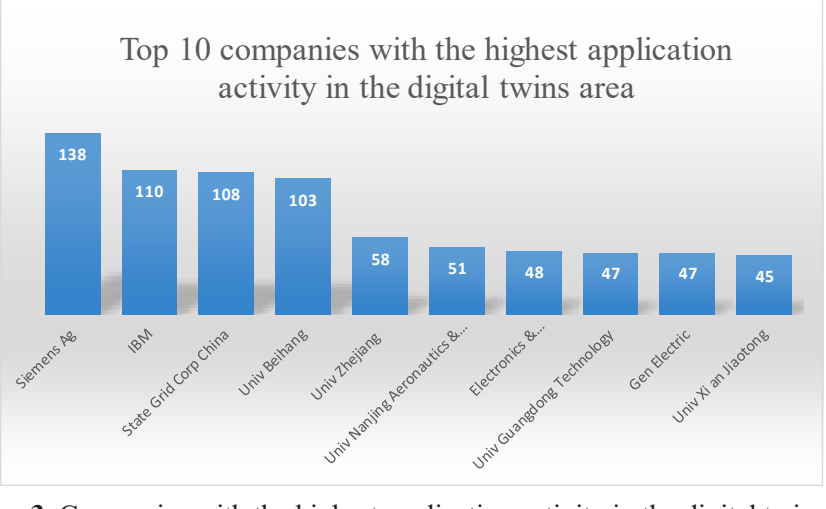

Figure 3. Companies with the highest application activity in the digital twins area
Source: Calculations based on results of completed patent searches in online databases –www.lens.org

8. Summary and recommendations of the patent research

After analyzing the results of the patent research, we could conclude that the application activity of companies creating technologies related to digital twins was null in the initial years of the patent research. In 2018, the applicant

activity increased, with a significant increase in the number of patent applications filed and patents granted from 2021 onwards, peaking in 2024, for which a total of 2433 results were found.

When analyzing the results of the research carried out on patent applications filed and patents granted by country and by subject digital twins, the first place is held by China with 5476 published results, and the second place is held by the United States with a total of 828 patent applications filed and patents granted. There is a very large gap between the top two countries, with China also ahead of the other territories examined. This trend is also observed in other innovative industries such as artificial intelligence and three-dimensional printing.

Considering the only one result identified for the territory of Bulgaria, we could recommend Bulgarian enterprises to invest in the development of new technologies for digital twins, patenting them nationally and internationally.

Conclusion

The digital twins ensure optimal business performance and production efficiency, thus leading to optimal results in the industries in which they are used. Digital twins are becoming a major tool for the modernization of manufacturing and industrial processes around the world. Digital twin technologies are helping global companies optimize their manufacturing processes, reduce costs, and improve quality. These solutions are used to monitor and manage complex systems such as factories, transportation networks, and energy infrastructures. On a global scale, digital twins are being used to support sustainable development and reduce carbon emissions. They play an important role in global supply chains by enabling real-time tracking and management of goods and in accelerating innovation by providing testing, simulation, and optimization capabilities before actual deployment in the industry. Applications of digital twin technology are evolving at an extremely rapid pace and are leading to changes in the way enterprises operate. Digital twins could significantly improve decision-making processes in data-driven enterprises. In order for enterprises to make the most of their technology, it would be useful to take steps to patent it at national or international level, thus giving them a competitive advantage over other companies in the market and enabling them to profit from their patents if they properly manage their industrial property. Because of the industry's rapid technological advancements, market experts predict that by 2028, the digital twin market will generate $110.1 billion in revenue, giving further reason for companies to protect technologies as industrial property objects.

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