

# DIGITAL TWINS AND THEIR APPLICATIONS IN THE INDUSTRY: A SYSTEMATIC LITERATURE REVIEW

## (GEMELOS DIGITALES Y SUS APLICACIONES EN LA INDUSTRIA: UNA REVISIÓN SISTEMÁTICA DE LITERATURA)

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### ABSTRACT:

Digital twin technology enables the creation of simulated representations of physical entities through simulations and predictions, which can help reduce costs and improve production in industrial settings. This technology is based on key aspects of Industry 4.0, such as Artificial Intelligence, the Internet of Things, and Big Data. This research aims to analyze the implementation of digital twins, their development, and their level of support within the industry. A systematic literature review was conducted on digital twins and their industrial applications, following a previously established review protocol. The results identified a set of fundamental components and technologies required for the implementation of digital twins in industry, as well as the extent of their use in manufacturing. It was concluded that Artificial Intelligence plays a fundamental role in the functioning of digital twins, and the potential benefits of incorporating this technology into the medical field were also highlighted.

*Keywords: Digital twins, Industry 4.0, Artificial Intelligence, Internet of Things, Big Data.*

### RESUMEN:

La tecnología de los gemelos digitales permite la creación de representaciones simuladas de entidades físicas mediante simulaciones y predicciones, lo que podría contribuir a la reducción de costos y a la mejora de la producción en las industrias. Esta tecnología se basa en aspectos característicos de la Industria 4.0, como la inteligencia artificial, el Internet de las Cosas y el Big Data. El objetivo de esta investigación es analizar las implementaciones de los gemelos digitales, su desarrollo y su grado de adopción en la industria. Se llevó a cabo una revisión sistemática de la literatura relacionada con los gemelos digitales y sus aplicaciones en el ámbito industrial, conforme a un protocolo de revisión previamente establecido.

Los resultados permitieron identificar una serie de componentes y tecnologías fundamentales necesarias para la implementación de los gemelos digitales en la industria, así como la magnitud de su participación en el área de la manufactura. Se determinó que la inteligencia artificial es una parte esencial para el funcionamiento de los gemelos digitales, y se destacó la relevancia de su incorporación en el campo de la medicina.

*Palabras clave: Gemelos digitales, Industria 4.0, inteligencia artificial, Internet de las Cosas, Big data.*

## I. INTRODUCTION

A digital twin (DG) can be understood as a virtual representation of a physical entity that enables simulations and the prediction of events [1]. The concept has been broadly defined by various researchers [2, 1, 3, 7], which has led to variations in its interpretation depending on the researcher and their field of expertise. This variability has also contributed to confusion with related technologies, such as digital models and digital shadows [1].

The main difference between DGs, digital models, and digital shadows lies in the nature of data connection and transmission. Digital models do not require automatic or continuous data processing from the physical model, serving only as static representations of a physical product. In contrast, a digital shadow is based on a physical object whose state must update in response to changes in that object; therefore, it typically involves a continuous one-way flow of data from the physical entity to its virtual counterpart. In summary, a DG differs significantly from these other technologies due to its requirement for two-way data exchange between the physical entity and its digital representation [2, 1].

It is important to examine DG implementation, as it has demonstrated numerous benefits across various fields. Industry, in particular, has gained significantly from DGs due to their potential to maximize economic returns while reducing costs [1]. Consequently, the inclusion of DGs in industrial settings is essential: when implemented correctly, they can profoundly impact efficiency at both national and international levels by improving process effectiveness.

## II. THEORETICAL FRAMEWORK

This section will explain some of the essential concepts related to DG. Likewise, the information presented is important for answering RQ1 and RQ2, which are described in detail in the methodology section. Therefore, the definition of the concept of DG, its characteristics, and the implications of implementing this technology are discussed.

### 2.1 DG (RQ1)

The concept of DG is generally attributed to Professor Grieves at the University of Michigan in 2003, who described it as the virtual representation of a physical object and its associated information. He also stated that DGs are composed of three parts: a physical product, its virtual representation, and a bidirectional connection, this last component

enabling constant information exchange between the physical and virtual parts [8].

The development of DG has contributed to the advancement of other Industry 4.0 technologies, such as Big Data, Artificial Intelligence, and the Internet of Things. This has enabled DGs to go beyond simple simulations of “real-world” products and, today, take on functions such as predicting future events and even providing solutions to potential failures. This is made possible by the application of Artificial Intelligence in DGs, which allows for the continuous exchange of data between the physical object or entity and its digital counterpart [9, 11].

Table 1 presents the characteristics or common elements identified in various definitions of DG.

Based on the characterizing aspects found in the different definitions reviewed in the systematic literature review, along with the characteristics summarized in Table 1, we propose the following definition of DG: a DG can be understood as a real-time virtual representation of a physical entity or process which, through technologies such as Artificial Intelligence, Big Data, and the Internet of Things, enables simulations and predictions of that physical entity.

*Table 1. Characteristics of DGs according to the referenced authors.*

Reference	Integration of technologies related to the Industry 4.0	Prediction function	Simulation function
[12]	×	✓	×
[9]	✓	✓	✓
[2]	×	×	✓
[8]	✓	×	✓
[1]	×	✓	✓
[13]	✓	✓	✓
[3]	✓	×	✓
[4]	✓	✓	✓
[14]	✓	✓	✓
[15]	×	×	✓
[16]	✓	×	✓
[17]	✓	✓	×
[18]	×	✓	✓
[19]	✓	✓	✓
[20]	×	×	✓

## 2.2 Characteristics of DGs

Various studies [9, 8, 21] have identified and described a number of characteristics associated with DGs, which have been classified into the following categories:

### 2.2.1 Entities and Environments

The entities and environments that make up DGs are divided into two main groups: those considered virtual and those belonging to the physical world [8]. That is, virtual entities are those that operate within a digital environment or serve as representations of physical objects. In this regard, it is important to clarify that, according to Professor Grieves's conceptualization of DG, a specific DG system or environment may include more than one virtual entity, each with its own functions and data records of the physical world, and these entities can interact with one another [8].

The virtual environment is the digital "space" that simulates a specific physical location in which the object or physical entity represented by the DG exists. In other words, the virtual environment acts as a mirror of the physical environment. In contrast, the physical entity is the object with tangible properties on which the DG is based. This entity does not necessarily have to be a single object; it can also be a more complex system with the necessary characteristics for digital representation, such as entire cities. For example, in the research conducted by [22], a DG was developed for the city of Dublin, Ireland.

Finally, the physical environment is the space in which the physical entity exists and interacts. Only the data necessary for the simulations performed by the DG are collected from this environment.

### 2.2.3 Status and Parameters

The state of a DG is defined as the condition of both the DG and its physical counterpart at a specific point in time. This state is determined using parameters, which are the types of data exchanged through the existing connection between them [8].

## 2.3 Implications of the Use of DGs (RQ2)

This section addresses the implications of using DGs, with a focus on identifying the associated benefits and costs of their implementation. Key considerations include the cost and duration of implementation, the development environment, and the execution process of the DG [1, 17].

The DG development and execution environment must have sensors capable of interacting in real-time with an Artificial Intelligence environment (physical–virtual) [17]. This interaction enables automated learning through data analysis, which in turn supports the optimization, monitoring, and forecasting functions of the DG.

It is necessary to mention that, given the vast amount of data generated by DGs, as well as those necessary for their creation and feedback, it is required to use Artificial Intelligence to improve the efficiency of data flow, allowing to identification of faults and quality defects on the digitally generated object.

The cost of implementing a DG is significant, as it requires personnel with specific competencies for developing the working environment and carrying out the implementation [1]. However, although the initial investment can be high, this cost tends to decrease over time. Once the DG is properly implemented, it enables cost savings by reducing the need for physical prototypes, allowing early identification of potential failures and quality defects, and supporting variations in production and functionality to achieve optimal design. These advantages of DGs help reduce both resource use and development time, as the creation of a physical prototype becomes unnecessary [5].

The development of a DG is a process that requires time. It is long and complex, as it must be guided, operated, and optimized in conjunction with various software tools, including those needed for Big Data analysis, as well as reliable sensor technology for data collection, processing, and interpretation. Therefore, ensuring synchronization between the DG and the physical environment is essential [17].

Consequently, although DGs are complex to implement due to the factors mentioned above, they can represent a significant improvement in modern industry, as noted by researchers [15, 17]. Their use can lead to increased productivity, improved efficiency, higher quality, and cost reduction in industries or companies that adopt them. However, it is also recognized that DGs are not always suitable, as they may introduce additional complexity into production and development processes.

### III. RELATED WORK

The systematic literature review made it possible to identify research works related to the application of DGs in industry, where the benefits and challenges of including this technology in the area are evidenced. In this sense, primary works that address the topic under study and allow answering RQ3 are examined.

In Spain, a study was conducted involving the development of a DG for a workstation dedicated to assembling parts produced through 3D printing [14]. The project followed several key steps, including the modeling of the station, the creation of an automation project, and the integration of the system into Industry 4.0-related architectures. Ultimately, a physical workstation was built based on the data and insights obtained from the DG developed during the study.

Other researchers in Spain generated a DG that allows to manage processes within an industrial laundry facility [23]. The study involved the creation of a model aimed at supporting decision-making, with linen processing as the primary operational focus. The DG provided relevant information to enhance production efficiency. The system's outputs closely aligned with the decisions typically made by human experts, demonstrating the potential of DGs to support and even automate decision-making processes.

Researchers from Canada and Pakistan implemented a DG to optimize the performance of the 5G network by creating a neural network that could predict the variable behavior of the network. This allows real-time monitoring and data collection, which were then fed into the neural network to facilitate autonomous network management. As a result, the system was able to accurately estimate network dynamics and support effective segmentation, ultimately leading to a near-optimal management policy.

In China, researchers conducted a study on DGs and intelligent manufacturing that has received increased attention due to the rise of Industry 4.0 technologies [15]. The study found that the use of DGs in advanced manufacturing enhances operational efficiency and enables the prediction of production failures, thereby supporting the implementation of preventive measures to reduce their impact.

In summary, it is evident that the implementation of DG has been promoted internationally, particularly in Europe, Asia, and North America. However, the primary studies analyzed do not provide evidence of the specific aspects that should be considered for its application in industry, revealing a gap in the literature that this study seeks to address.

### IV. METHODOLOGY

This section describes how the information supporting the research was obtained and processed, from the research approach to the results obtained with the selection processes. Section 4.1 presents the approach used in the research, followed by a description of the study population in section 4.2. Finally, section 4.3 describes the data collection techniques, the inclusion and exclusion criteria for selecting primary sources, and the preliminary and final selection processes.

#### 4.1 Research Approach

This research adopts a qualitative approach based on how the data were obtained and subsequently analyzed. The primary studies were examined through a systematic literature review, using the protocol established by Kitchenham as a reference [25]. This process enabled the identification of relevant information about DGs and their applications in the industry, addressing three research questions: RQ1. How has the term "DG" been defined and characterized? RQ2. What are the implications of implementing a DG? and RQ3. In what ways have DGs been applied in the industry, and what are the antecedents in this regard? These research questions supported the objective of the study, which is to define DGs and demonstrate their applications in the industrial context.

#### 4.2 Study Population

For this research, the primary studies regarding DGs and their applications in industry constitute the study population. These documents include definitions of DGs and descriptions of how this technology has been implemented in industrial contexts.

#### 4.3 Data Collection Technique

To locate the primary studies on DGs and their applications in industry, a search was conducted in indexed databases specializing in scientific and academic publications, such as IEEE Xplore Digital Library, ScienceDirect, and SpringerLink [26]. Keywords in both Spanish and English were used: gemelos digitales (DGs), industria (industry), and manufactura (manufacture), along with search strings combining these keywords across both languages.

## 4.4 Information Processing

For the processing of the information, inclusion and exclusion criteria were established for the bibliographic sources, including the following:

### 4.4.1 Inclusion Criteria

They are the set of criteria used to determine whether an article should be included in the literature review. These criteria are:

- Primary documents written in English or Spanish.
- Primary documents whose main topic is related to the term DGs.
- Primary papers that gather experiences or research results concerning the application of DGs in industry.
- Primary papers published between 2018 and 2022.

### 4.4.2 Exclusion Criteria

These are the set of guidelines that exclude an article from being contemplated in the literature review:

- Studies for which full-text access was not available.
- Studies derived from other studies.
- Papers published in journals or conference proceedings without international peer review.

### 4.4.3 Preliminary Selection Process

After applying the search criteria described above, a total of 156 primary studies were identified. The preliminary selection process involved analyzing the titles, abstracts, and keywords of these studies, which allowed for the exclusion of documents that were not relevant to the present research. As a result, 40 documents were selected for further review.

### 4.4.4 Final Selection Process

Once the results of the preliminary selection were obtained, a full reading of the identified primary studies was conducted, followed by the preparation of corresponding technical data sheets. These sheets compiled key information from each document (objectives, methodology, and results) in order to determine which studies aligned with the objective of this research. As a result, 30 documents were selected.

Of the total number of selected documents, 16 were used to address RQ1, which relates to the definition of DG. Four references contributed to answering RQ2, focused on the implications of DG implementation. Finally, 15 studies were used to address RQ3, concerning the application of DG in industry. It is important to note that some documents provided information relevant to more than one research question.

## V. RESULTS

Based on the systematic literature review, several ways in which DGs have been applied across different areas of industry were identified. Therefore, this section presents an analysis organized according to the categories and criteria defined for this purpose, which are:

- A. General Aspects – This category includes criteria related to language and country of origin of the studies.
- B. Technological Aspects – This category comprises criteria for the components and technologies used to operate DG applications. The selection of these criteria is based on the contributions of relevant researchers in the area [1], [17], particularly regarding the technologies involved in DG development.
- C. Application Aspects – This category includes criteria related to the size and classification of the industries in which DGs have been implemented.



Fig. 1. Categories and criteria for analysis.

The following describes the criteria to provide a clearer understanding of the study categories.

### A. General Aspects

This category includes two criteria: the country in which the DG application was developed and the language in which it was documented:

- Country – This criterion identifies the country where the DG application was developed.
- Language – This criterion refers to the language in which the DG research was published.

### B. Technological Aspects

This category includes two criteria related to the components involved in DG operation and the enabling technologies used in their development:

- Enabling Technologies – This criterion refers to the technologies used to plan, develop, and implement DGs. These are typically associated with Industry 4.0, and the values considered for this criterion include Big Data, Artificial Intelligence, Internet of Things, Cyber-Physical Systems, and Machine Learning.
- Functional Characteristics of DGs – This criterion identifies the key elements that constitute a DG and are essential for its optimal functioning. Possible values include data analysis, object simulation, and self-learning.

### C. Application Aspects

This category includes two criteria related to the type of industry in which DGs were implemented and the dimension or scale of the DGs:

- Types of Industries in Which DGs were Implemented – This Criterion Classifies DG Applications Based on the type of industry in which they were applied. Possible values include the food industry, manufacturing, automotive, among others.
- DG Dimension – This criterion categorizes DG applications according to the size or scope of the system, which can be classified as either a single system or a large-scale system (composite system).

The following section presents a detailed description of the results obtained through the application of each analysis criterion.

## 5.1 DG Applications Selected for Analysis

Based on the systematic literature review, a set of DG applications was selected for analysis to address RQ2 and RQ3. Table 2 presents the studies related to DG applications, organized by country of origin.

*Table 2. Studies related to DG applications by country of origin.*

Reference	Country
[12]	Spain
[9]	Spain
[2]	China
[8]	China
[1]	China
[13]	China
[3]	Finland
[4]	United States of America
[14]	Germany
[15]	China
[16]	China
[17]	Korea
[18]	China
[19]	United Kingdom
[20]	China

In the same vein, Table 3 provides a brief description of each DG application experience based on the selected primary case studies, with references to the researchers who conducted them.

Table 3. Description of DG applications according to referenced authors.

Reference	Application description
[12]	Parts assembly station with different tools and a series of established steps; simulation and integration of industrial assets.
[9]	Operations management of industrial laundry, generated from the factory study; this DG is intended to support decision-making within the factory
[2]	B5G network to perform an optimal cutting policy using neural networks and reinforcement learning.
[8]	Asset management of a sustainable smart factory to optimize processes.
[1]	Power plant to generate trend predictions, better water management, increased efficiency, and reduced emissions.
[13]	Monitoring the transformation of sea waves into renewable energy, using technologies such as neural networks to generate a prediction of the data for DG development.
[3]	Automatic generation of DGs for intelligent manufacturing systems to control automated vehicles, enabling their autonomous movement through workspaces.
[4]	Connected and automated vehicles based on the Unity graphics engine, implementing different subsystems to satisfy the different preferences of each driver.
[14]	Manufacturing production, optimization of factory processes.
[15]	Risk assessments on highways are based on the analysis of vehicle trajectories and behaviors, obtained through aerial footage captured by drones and other surveillance equipment at the sites.
[16]	Satellite assembly station, in order to improve efficiency through a real-time control of the manufacturing process assets, which allows to organize them and make predictions based on the data obtained from the physical space.
[17]	A DG based on a vertical farm is implemented to monitor the state of the crops from data obtained from devices in the physical farm.
[18]	Based on reinforcement learning techniques, the DG adopts training functions to automate intelligent production systems.
[19]	Development of a DG for a utility system of a chemical plant, which allows site personnel with data on different parameters related to plant operations. Additionally, it presents prediction functions on future failures and simulation of hypothetical cases for better preparation for these events.
[20]	Using a DG to manage vehicular traffic from network data with Edge Computing functions, which allows analyzing and predicting the state of the networks, and obtaining benefits such as reduced vehicular congestion.

## 5.2. Analysis of the Results Based on The Evaluation Criteria

This section presents the results of the analysis conducted on the selected DG applications, organized according to each criterion within the defined analysis categories.

### A. General Aspects

Regarding the results of the analysis for the criterion related to the country in which the DG was developed, Figure 2 shows that 46.6% (7) of the references correspond to studies conducted in China. Spain accounts for 13.3% (2), while the United States, Canada, Germany, the Republic of Korea, Finland, and the United Kingdom each represent 6.6% (1). This suggests that the implementation of DG has gained greater relevance and

usage in Asia. Additionally, its growing presence can be observed in various European countries. In the Americas, initiatives are evident only in Canada and the United States.

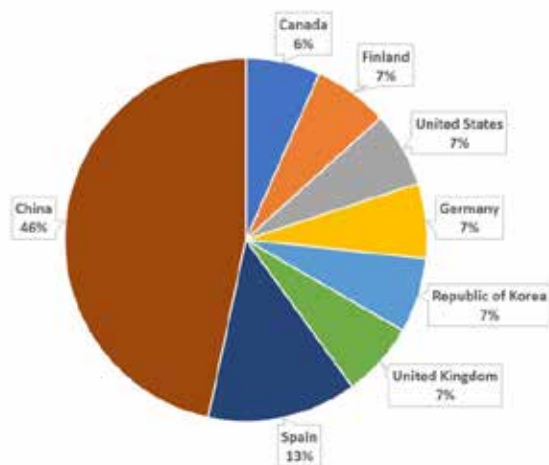


Fig. 2. Country where the DG was developed

Regarding the language criterion, Table 4 shows that 87% (13) of the analyzed applications were documented in English, while 13% (2) were in Spanish. This may be due to the fact that English is a universal language, enabling researchers to reach a broader international audience.

Table 4. Language of primary studies of DG applications

Reference	Language
[12]	Spanish
[9]	Spanish
[2]	English
[8]	English
[1]	English
[13]	English
[3]	English
[4]	English
[14]	English
[15]	English
[16]	English
[17]	English
[18]	English
[19]	English
[20]	English

## B. Technological Aspects

With respect to the Enabling Technologies criterion, Table 5 shows that 87% (13) of the analyzed studies highlight the importance of implementing Artificial Intelligence in the development of DGs, followed by the use of the Internet of Things.

Table 5. Enabling technologies for the development of a DG

Reference	Big Data		Artificial intelligence	Machine Learning	Cyber-physical system
[12]	✓	✓	✓	×	✓
[9]	×	×	✓	×	×
[2]	×	×	✓	✓	×
[8]	✓	✓	✓	×	×
[1]	✓	✓	×	✓	×
[13]	✓	×	✓	×	×
[3]	×	×	✓	×	✓
[4]	×	×	✓	✓	×
[14]	×	×	✓	×	×
[15]	×	×	✓	✓	×
[16]	✓	✓	✓	✓	✓
[17]	✓	×	✓	×	×
[18]	✓	✓	✓	✓	✓
[19]	×	×	×	×	×
[20]	✓	×	✓	✓	×

As for the criterion Functional characteristics of DGs, Table 6 shows that data analysis (87%, 13 studies) and object simulation (80%, 12 studies) are considered essential features for DG operation. These characteristics enable interaction within the virtual model without the constraints of the physical system and support decision-making based on the DG's behavior across various scenarios.

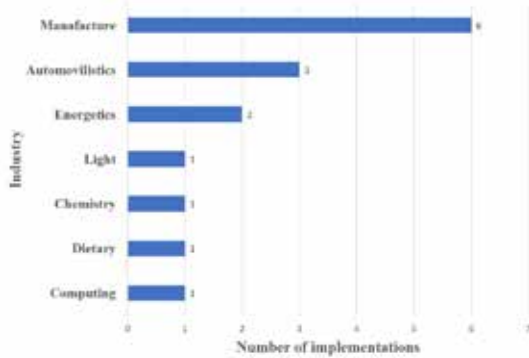
Table 6. Functional characteristics of DGs

Reference	Data analysis	Simulation of the object	Self-study
[12]	✓	✓	×
[9]	✓	✓	×
[2]	✓	✓	✓
[8]	✓	✓	×
[1]	✓	✓	✓
[13]	×	×	×
[3]	✓	×	×
[4]	✓	✓	✓
[14]	✓	✓	×
[15]	✓	✓	✓
[16]	✓	✓	✓
[17]	×	×	×
[18]	✓	✓	✓
[19]	✓	✓	×
[20]	✓	✓	✓

### C. Application Aspects

According to the criterion Areas in Which DGs Were Implemented, the analysis revealed that 40% (6) of the applications focused on improving the efficiency of manufacturing processes, as shown in Fig. 3.

Fig. 3. Types of industry in which DGs have been implemented



Note: The numbers in the bars indicate the reference number of the applications according to Table 3.

Regarding the DG Dimension criterion, Table 7 shows that 33% (5) of the applications refer to DGs composed of other DGs or integrated with other IT systems. In contrast, 67% (10) of the analyzed applications involve individual DGs, meaning their functionality does not depend on other systems.

Table 7. Dimension of the DG

Reference	Individual system	Compound system
[12]	✓	×
[9]	✓	×
[2]	✓	×
[8]	×	✓
[1]	✓	×
[13]	✓	×
[3]	×	✓
[4]	✓	×
[14]	×	✓
[15]	✓	×
[16]	×	✓
[17]	✓	×
[18]	✓	×
[19]	✓	×
[20]	×	✓

In summary, from the literature review and the analysis criteria applied, it is evident that DGs have been mostly implemented in China, whose reference data are mostly socialized in English. Then, the use of AI for their development is highlighted, where characterizing aspects, such as data analysis and simulation, stand out for their operation-being implemented to improve the efficiency of manufacturing processes.

## VI. CONCLUSION

The technology and concept of DG have evolved significantly from the early 21st century to the present, driven in large part by advancements in Industry 4.0 technologies. Based on the research questions addressed in this study, it was possible to identify key definitions and characteristics of DGs, understand the implications of their development, and examine how they have been applied across various types of industries.

Concerning the definitions, the concept of DG and its associated characteristics were clarified, allowing for a better understanding of the technology. Furthermore, the evolution of the concept was traced back to the initial proposals by Grieves and Vickers [12]. Based on the findings from the literature review, a definition was proposed to reflect the current understanding of DG.

Regarding the implications of DG development, the literature highlights its close relationship with other Industry 4.0 technologies in both its creation and operation [1], [17]. Among these, Artificial Intelligence (AI) emerges as a fundamental component for the effective functioning of a DG.

In terms of DG applications across different industries, the manufacturing sector receives the greatest focus for DG implementation. This finding aligns with previous research that provides evidence of how DGs are being applied within industrial contexts [13], [9].

The results of the systematic literature review may hold significant relevance at both national and international levels for researchers and industries interested in the use and implementation of DGs. This study can serve as a reference point for understanding the current state of DG implementation in the industrial sector.

Finally, it is considered necessary to conduct further studies on DGs in other fields of knowledge, such as medicine, which, based on the findings of this research, could greatly benefit from the application of DG technologies.

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