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Review

Smart Retrofit: An Innovative and Sustainable Solution

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Abstract: Recovering old machinery, once it reaches its end of life, allows companies to be sustainable. Several strategies are available for this purpose, both from the point of view of hardware and software modifications. Especially in the industrial sector, these strategies are classified as revamping, remanufacturing and retrofitting. Machinery revamping, retrofitting and remanufacturing are all used to improve industrial equipment performance, efficiency and sustainability. Each approach has unique benefits and trade-offs, depending on the specific needs and requirements of the equipment and business. Moreover, according to Industry 4.0 principles, it is also possible to talk about smart retrofitting, involving the integration of various technologies such as sensors, automation systems, Digital Twins, artificial intelligence and data analytics software to control and optimise the operation of the machinery. Digital Twins, in particular, have been widely used among smart retrofit solutions and can integrate several innovative aspects of dated systems. However, a literature review needs to clarify their meaning and specific characteristics. For this reason, this paper aims to distinguish different strategies and find a correct definition of smart retrofitting, highlighting its relevance, benefits and sustainability in the industrial sector, focusing more on Digital Twin solutions for smart retrofitting.

Keywords: Industry 4.0; Industrial Internet of Things; sustainability; Digital Twin; smart manufacturing; Cyber Physical System

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1. Introduction

Industry 4.0 was born in Germany in 2011, but not all companies born after 2011 are “smart factories”, and many do not meet the eligibility requirements for Industry 4.0 (I4.0). The key elements of I4.0 are the Industrial Internet of Things (IIoT) and Cyber-Physical Systems (CPS) [1]. The fundamental advantage provided by such developed CPS systems, which stand out by combining a physical configuration with their respective digital counterparts, is the realisation of what is known as a “Digital Twin” (DT). Cloud systems, appropriate communication protocols and smart systems will be needed to enable these typical I4.0 tools. Several strategies are implemented to bridge the gap between traditional and smart factories. One technique is purchasing new machinery to replace existing dated machinery. Smart retrofitting is another technique used to turn an old machine into a machine for a smart factory. A retrofit provides a quick, inexpensive and straightforward solution compared to introducing new machines [2]. For this reason, retrofitting is often implemented by small or medium-sized enterprises (SMEs) [3].

The traditional retrofit involves the insertion of advanced sensors, actuators and controllers into existing machinery and manufacturing systems to achieve the homogeneity of machinery required in manufacturing plants [4]. This aspect makes it possible to achieve added value, in terms of quality and productivity, by taking advantage of existing equipment. In this way, the use phase of such machinery can be extended, increasing the number of applications; these new applications contribute to the economic and environmental sustainability of companies [5]. Thanks to the development of new technologies, it is possible to talk about digital or smart retrofitting. Smart retrofitting goes beyond industrial automation, sensing and control [6]. Smart retrofitting focuses on the software side much more than retrofitting. Artificial intelligence, machine learning algorithms, the use of neural networks [7,8], Digital Twins [2], cloud systems and programs for remote information management [9] are implemented. Combining all these technologies and adding human knowledge, it is possible to realise the "digital triplet" that is another intelligent solution to realise smart retrofit actions.

All this is achieved if smart sensors, Programmable Logic Controllers (PLCs) and controllers are also implemented on the hardware side. Moreover, with smart retrofit actions, it is possible to integrate such tools on older machinery that does not have them [10].

Bakir and Ehrlich et al. report that these implementations can be done on old and new systems [11,12]. The purpose of the old machine is to adapt to the I4.0 paradigm and/or implement functionality; for the new machine, the goal is to keep up with new technology (which is developing day by day) and be able to integrate it. In addition, smart retrofitting action enables benefits related to sustainability. The sustainability brought by retrofit actions can be defined in terms of environmental sustainability related to the reuse of machinery, resource optimisation and reduction in waste [13]; economic sustainability in terms of the decrease in costs, waste and time [14] and increase in productivity [11,12]; and social sustainability, ensuring greater safety and integration of the operator in the workplace [15,16], helping him make decisions and value his work [17].

The following is a literature review in which an attempt is made to highlight a clear definition of smart retrofitting. It is necessary to identify a clear definition because many articles confuse the meaning of "retrofit" or "smart retrofit" with "revamp" and "remanufacture". The term "revamp" denotes all actions that lead to a mechanical renovation of a machine; the word "retrofit", on the other hand, denotes performance improvement actions, implementation of new technologies or controls and new, helpful services related to the machine. Thus, the activity described by Bunterngchit et al. [15] can be considered a "revamp" action because it implements mechanical hardware actions and replaces old parts.

Another aspect from which smart retrofitting must be differentiated is "remanufacturing". Remanufacturing involves the disassembly, cleaning, replacement, reworking, assembly and testing of components that are close to the end of their life but can be redeveloped as new after these steps [18,19]. Remanufacturing focuses mainly on physical elements, components and machine parts and does not involve software, interfaces or connectivity of the machines. Moreover, remanufacturing does not integrate new technologies but reworks materials already in the old system to give it new life [20]. Smart remanufacturing works in the same area of remanufacturing, but it uses "smart" technologies such as additive manufacturing (AM) and "smart" sensors to remanufacture damaged or worn parts [21].

On the other hand, there is no marked difference between retrofitting and smart retrofitting. However, it is possible to denote those retrofit actions that implement machine learning algorithms, neural networks and other recently developed technologies via smart retrofitting. In addition, smart retrofitting emphasises the implementation of software systems, Digital Twins and machine learning algorithms in old machines to integrate them with other "smart" devices. A Digital Twin, in particular, is a technology that enables, together with the integration of intelligent sensors, the transformation of obsolete machine systems into a low-cost, intelligent and user-friendly system that enables condition monitoring, project management data and access to process data, with the ultimate goal of developing more user-centred CPS [22]. Another goal of smart retrofitting is the performance of predictive maintenance by introducing the influence of a virtual model of the physical counterpart and mitigating high-risk incidents for technicians and industrial assets. This factor can always be solved by implementing all the equipment and technologies provided by Industry 4.0. Digital Twins and machine learning algorithms can identify and predict future faults rather than only those currently evident and existing.

Current implementations and benefits of retrofitting and smart retrofitting are reported below. In particular, the article search methodology and the main retrofitting strategies are explained, from which the following questions can be answered:

1. What is smart retrofitting?
2. What are smart retrofit actions?
3. What are the main benefits?

Section 2 reports the research methodology with the keywords used and the definition of smart retrofitting; Section 3 highlights why and how retrofit actions are implemented—what are the main drivers and what are the leading technologies adopted and with what benefits; finally, Section 4 is the summary and conclusion of the paper.

2. Retrofitting and Smart Retrofitting: Materials and Methods

The analysis was conducted by searching all scientific articles, conferences and journals in English published in bibliographic databases. In particular, Scopus and ScienceDirect were the databases chosen for investigation. Searching in these databases requires keywords related to the field of interest. Keywords are searched in the titles, abstracts and keywords sections of the documents. Only documents containing keywords at least once are returned as results.

The first search was conducted in Scopus with the keyword “retrofit*”. This search yielded 45,880 results. As it was impossible to analyse all the articles, it was necessary to apply limitations with filters. As a first step, the production trend per year of the documents, identified with the key “retrofit*”, was analysed.

As Figure 1 shows, the number of publications related to “retrofit*” has increased significantly since around 2014 (there are about 2000 articles written in that year, and the production of articles since 2014 has been growing faster and faster). In fact, in 2011, the concept of “Industry 4.0” was presented for the first time. In the following years, concepts such as the Internet of Things, Cyber-Physical Systems and machine learning algorithms began to be applied [1]. These technologies have certainly given a boost to the application of retrofitting. For this reason, it was decided to narrow the search to a period between 2014–2023 (Figure 2). With this new filter, 23,502 documents were identified.

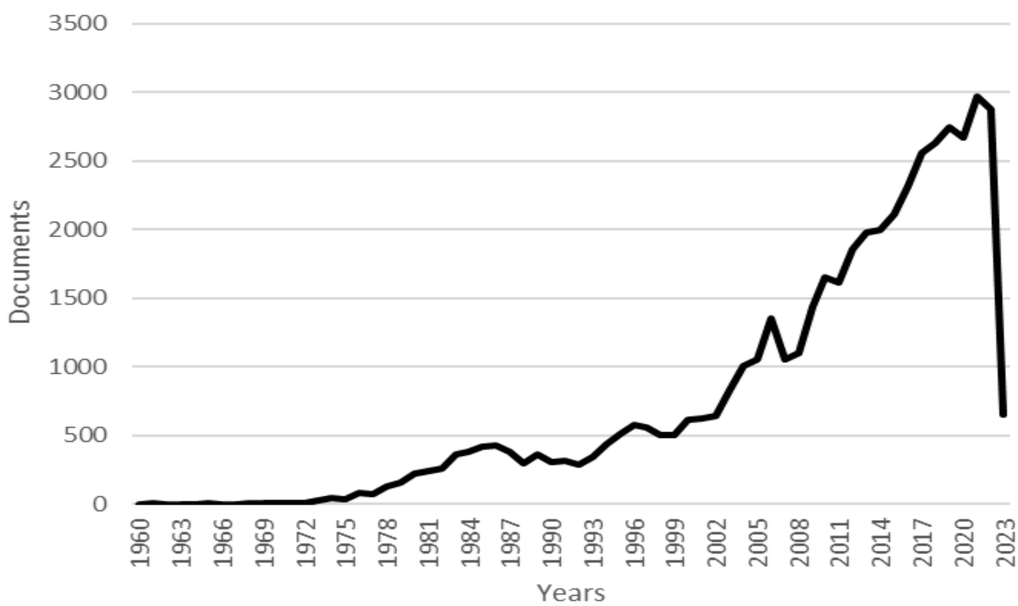

Figure 1. Documents by years—”retrofit*”—Scopus.

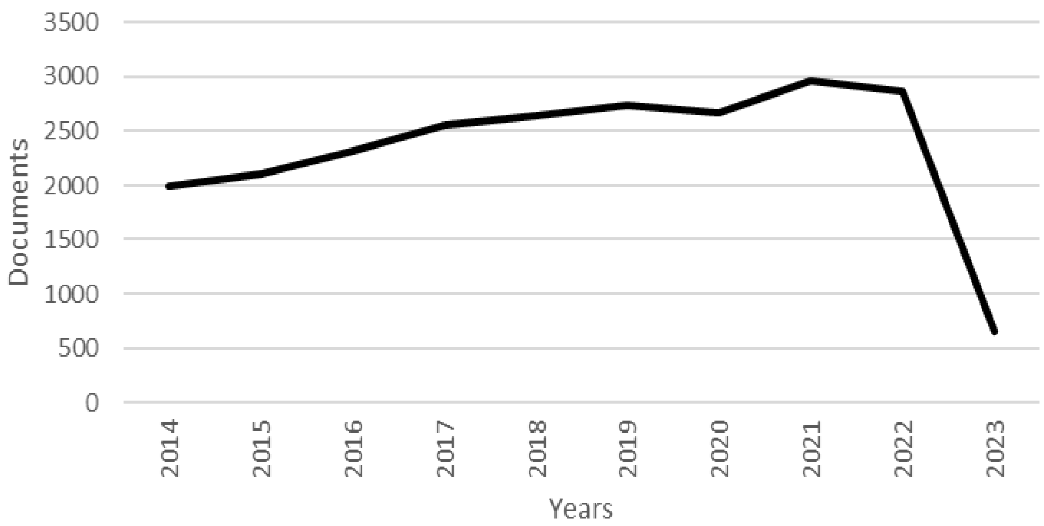

Figure 2. Documents by years—"retrofit*"—Scopus—2014–2023.

Moreover, many subject areas are affected by this topic. The focus is mainly on the "engineering" area, which covers 35.5 per cent of the literature about retrofitting. However, there are other subject areas: energy (11.1%), environmental science (9.9%), materials science (7.9%), earth and planetary sciences (5.6%), computer science (5.9%), chemical engineering (3.2%), social sciences (4.9%), physics and astronomy (3.1%), mathematics (3.4%) and others (9.5%).

Regarding the geographic areas of production of scientific research about retrofitting, most papers were written in the United States, followed by Italy, China and the United Kingdom (but with lower numbers). The retrofit-related documents produced by each country are shown in Table 1. This research may reflect the interest of each state in developing, implementing and scaling up such strategies in its own companies.

Table 1. Documents by country—"retrofit*".

Country	Documents
United States	4350
Italy	3095
China	2830
United Kingdom	1965
India	1325
Germany	1125

Despite applying this last filter, the number of documents was still high and covered several sectors. Therefore, to focus more attention on the sector of interest, it was decided to add additional keywords to "retrofit*" to target the search on production and industrial sectors.

For this reason, a second search was performed with the keys "retrofit* AND machin* AND industr*" and limiting the years to 2014–2023. The result produced by the search saw 287 document results. By reading the titles of the articles identified, it was possible to select 22 articles and realise that many documents were related to construction and chemistry. Therefore, although the search field was narrowed, more was needed.

Therefore, it was possible to proceed with a search between 2014–2023 with the keys "retrofit* AND machin* AND industr* AND (internet OR smart* OR cyber*)". There were 86 papers as a result. An evaluation of these 86 papers was made based on the information in the abstract, introduction and conclusion. Of these, only 18 articles were selected because they were inherent to, or related to, the industrial sector.

In addition to these articles, search results with the key 'smart retrofi*' were added. As a result, the search produced 31 results (Figure 3).

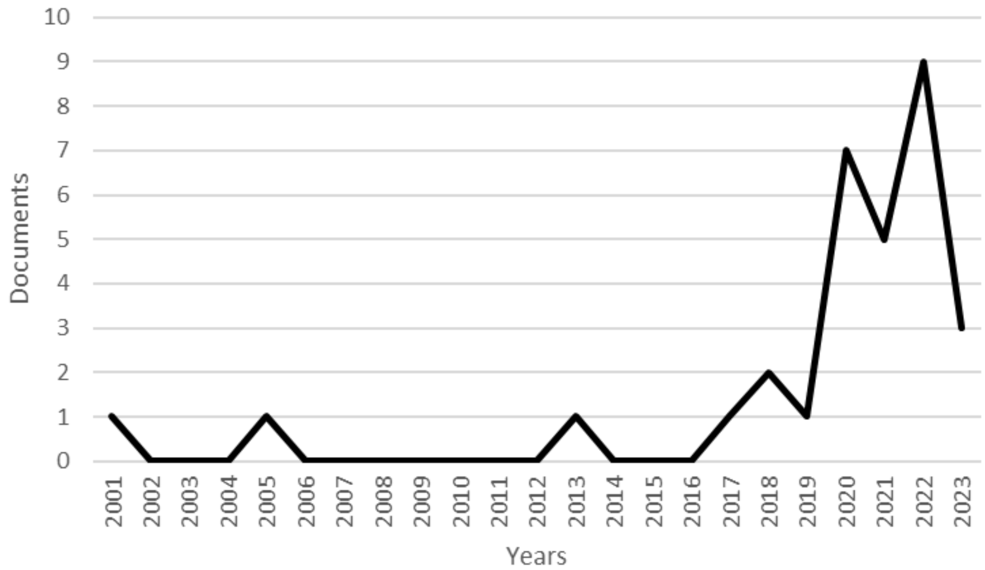

Figure 3. Documents by years—"smart retrofit*"—Scopus.

The analysis of the development trend of the articles by year shows that interest in smart retrofitting is recent. It is logical to think that the increasing use of machine learning algorithms and artificial neural networks has contributed to the development of this strategy. For consistency with the previous research and the above reasons, results between 2014–2023 were selected. The analysis of subject areas shows that smart retrofitting involves the engineering (35.0%), information technology (13.3%) and energy (13.3%) sectors. These results are justified by the fact that the main applications of smart retrofitting involve the use of new human–machine interfaces, machine learning algorithms, artificial neural networks (and thus the IT sector), resource optimisation systems (including energy) and performance (engineering sector).

Then, new keywords were added to the search key to focus on I4.0: "smart retrofit*" AND "industr* 4.0". Following an analysis of the abstracts, introductions and conclusions of the 11 documents, it was possible to select 4 articles.

Subsequently, searches were conducted in the other bibliographic database, ScienceDirect, to introduce further articles. Using ScienceDirect and the "smart retrofitting" (Figure 4) and "smart retrofitting industry 4.0"(Figure 5) keys, it was possible to access new articles of interest. The first search returned 5353 results and the second 667.

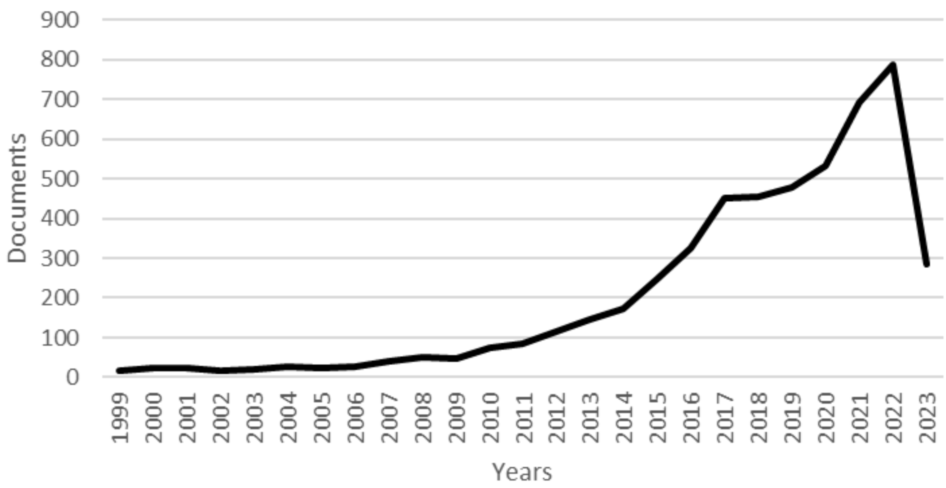

Figure 4. Documents by years—"smart retrofitting"—ScienceDirect.

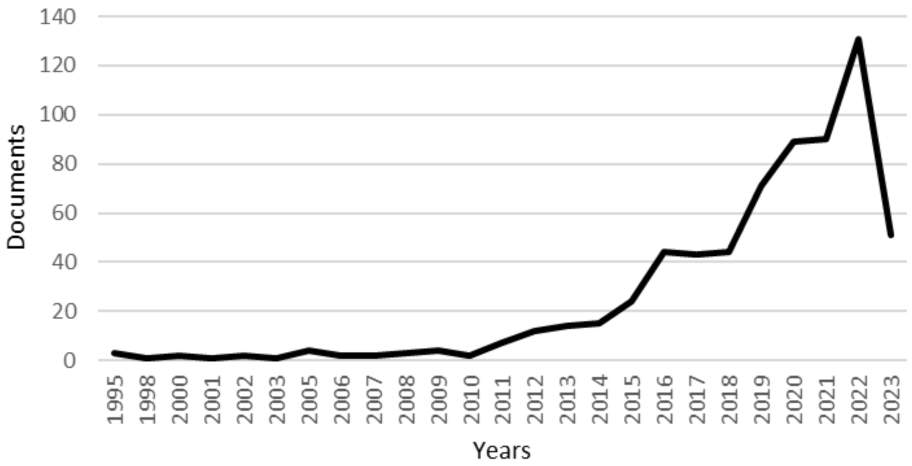

Figure 5. Documents by years—"smart retrofitting industry 4.0"—ScienceDirect.

Analysing the trend of publications by year for both keys, there is an increase after 2014. Therefore, for the same reasons as in the previous case, articles published between 2014–2023 were taken into account. This filter reduced the number of documents found to 4425 and 667, respectively. The two research results' abstracts, introductions and conclusions highlighted 20 and 9 papers as being of interest, and these were selected.

Then, VOSviewer, a software tool for constructing and visualising bibliometric networks, was exploited. With this software, it is possible to highlight primary recurrences and their connections(Figure 6).

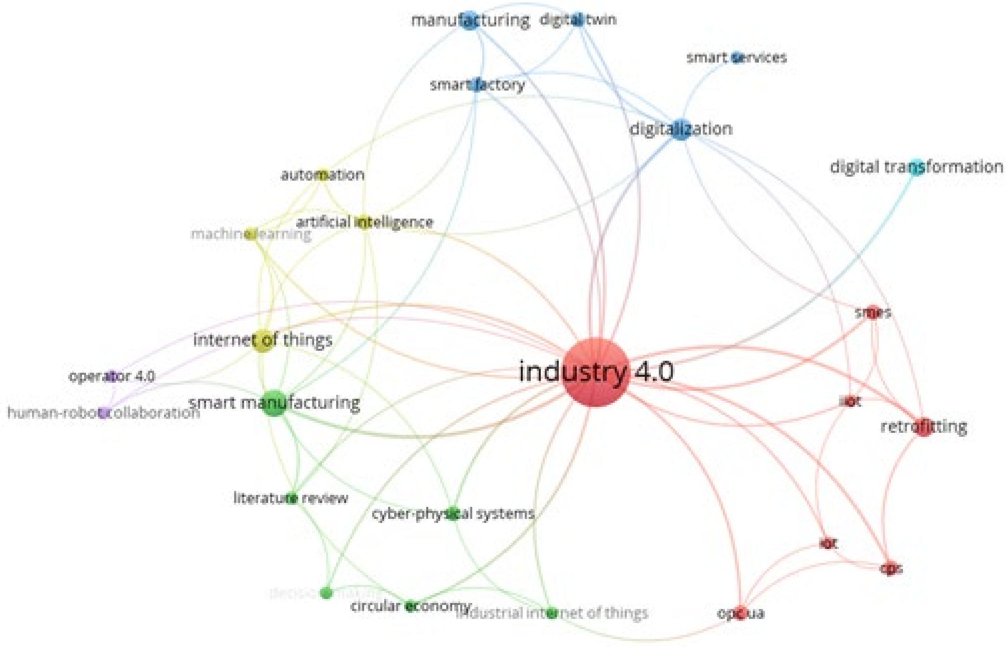

Figure 6. VOSviewer results—"smart retrofitting industry 4.0".

Recurrences allow us to go and assess where "smart retrofitting" fits in and with which technologies. Indeed, it highlighted words such as "artificial intelligence", "digital twin", "digital transformation", "IIoT", "cyber-physical system", and "internet of things", but also "operator 4.0" and "circular economy".

Most of these aspects are the same as those involved in the "digital triplet" [23]. In order to complete the triplet, in addition to virtual spaces, physical spaces and their connections, it is necessary to integrate the knowledge and experience of engineers and workers (including, in particular, knowledge of operator 4.0).

All these words allow us to add more keywords to searches, but they also give us an anticipation of how and what is "transformed" as a result of a retrofit action.

A few more papers of interest can be obtained by conducting scattered searches again with keys like those used previously and with the keywords highlighted by the probe in VOSviewer. Figure 7 reports the research conducted on the different bibliographic databases.

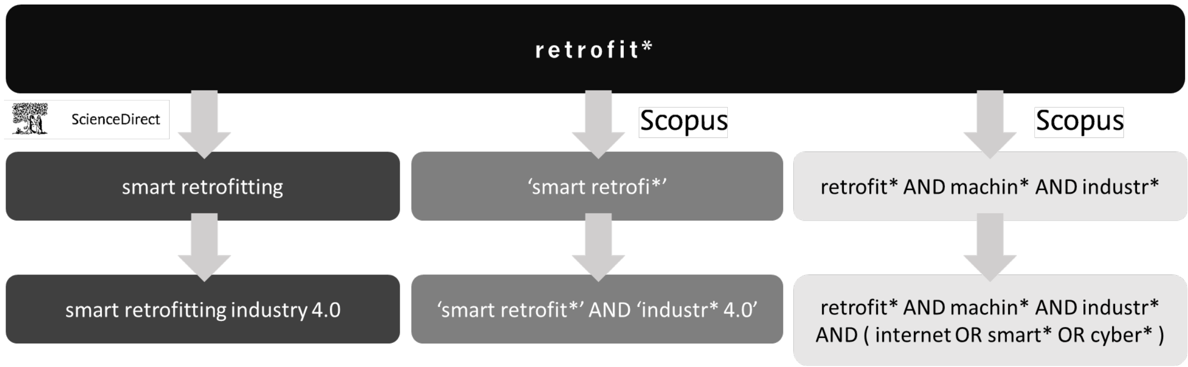

Figure 7. Research scheme.

Table 2 shows the number of papers found per search key in the various bibliographic databases and how many articles were relevant to each.

Table 2. Research keys and relevant results.

Database	Key	# of Papers	# of Relevant Papers
Scopus	retrofit* AND machin* AND industr*	287	22
Scopus	retrofit* AND machin* AND industr* AND (internet OR smart* OR cyber*)	86	18
Scopus	"smart retrofit*"	31	9
Scopus	«smart retrofit*» AND «industry* 4.0»	11	4
ScienceDirect	smart retrofitting	4425	20
ScienceDirect	smart retrofitting industry 4.0	667	9

Therefore, Table 3 relates to the research reported, specifying search keys and items identified. An article can be identified by searching with different keys. In addition to Table 3, this paper cites other articles.

Table 3. Research on Scopus and ScienceDirect.

Journal	**Scopus**	**Scopus**	**Scopus**	**Scopus**	**Science Direct**	**Science Direct**
Key	**«Smart Retrofit*»**	**«Smart Retrofit*» AND «Industry* 4.0»**	**Retrofit* AND Machin* AND Industr***	**Retrofit* AND Machin* AND Industr* AND (Internet OR Smart* OR Cyber*)**	**Smart Retrofitting**	**Smart Retrofitting Industry 4.0**
[24]					X	
[25]			X		X	
[26]			X		X	
[27]					X	
[10]			X	X		X
[28]			X	X	X	X
[29]				X		
[3]			X			X
[13]	X	X	X	X		
[30]			X	X	X	
[31]					X	
[9]	X					

Table 3. *Cont.*

Journal	Scopus	Scopus	Scopus	Scopus	Science Direct	Science Direct
Key	**«Smart Retrofit*»**	**«Smart Retrofit*» AND «Industry* 4.0»**	**Retrofit* AND Machin* AND Industr***	**Retrofit* AND Machin* AND Industr* AND (Internet OR Smart* OR Cyber*)**	**Smart Retrofitting**	**Smart Retrofitting Industry 4.0**
[32]					X	
[11]					X	
[33]					X	
[34]					X	
[35]			X	X		
[36]			X	X	X	
[37]				X		
[7]	X					
[38]	X		X			
[39]					X	
[5]					X	
[15]					X	
[40]					X	
[41]			X	X		
[42]						X
[43]			X	X		X
[44]			X	X		X
[17]	X	X	X	X		
[16]	X	X	X	X		
[45]	X				X	X
[4]	X	X	X	X		X
[2]				X		X
[12]					X	
[46]	X					
[47]			X	X		
[22]			X	X		
[48]			X	X		
[14]			X			
[49]			X			
[50]			X			

Smart Retrofitting: Definition

When analysing the literature, one comes across numerous definitions of smart retrofitting. Sometimes the term "retrofit" is misused to refer to actions that should instead be understood as smart retrofitting. Taking advantage of the Scopus search tool with the keyword "smart retrofit*", only 19 articles selected highlight a definition of this concept. A careful reading of the documents helps to identify a definition and its essential aspects. Sometimes several articles capture similar aspects of smart retrofitting.

The categories shown on the first line are those most frequently used in definitions of "smart retrofit*". The definition of SR provided by this article is derived from the combination of the analysed items.

Table 4 shows that most articles see "smart retrofit*" as *an innovation of legacy machines, introducing sensors capable of sending data related to production and/or machinery status. These data are then reprocessed to provide helpful information for production, maintenance, product and service quality. This activity is sustainable in several respects as it allows the reuse of machinery; environmental and economic sustainability aspects are easily deducible. Social sustainability is also encouraged because, through smart retrofit actions, it is possible to increase safety for the operators and enhance their work. In addition, it is essential to develop software capable of controlling, simulating or performing analysis concerning all aspects of plants or industrial systems.*

Table 4. Definition of smart retrofit*.

Reference	Innovation of Legacy System	Extend the Life Cycle of the Machinery	Low-Cost Implementation	Rapid Implementation	Implementation of Modern Technology	Optimisation of Resources	Sustainability	Integration of Simulation/ Analytic Tools	Real-Time Control	Production Benefit (Productivity, Quality)
[46]	X	X	X	X	X					
[16]	X	X	X		X	X				
[38]		X				X	X			
[13]				X		X		X	X	X
[17]	X		X	X				X		
[7]	X							X	X	
[37]	X							X	X	
[41]	X							X	X	X
[14]	X		X	X			X		X	
[2]	X									
[10]	X	X	X	X						
[49]	X						X		X	
[8]	X								X	
[42]	X		X							X
[43]	X							X	X	
[44]								X	X	X
[4]		X	X						X	
[39]			X						X	X
[11]	X		X	X					X	X

Comparing this definition with the one identified by Jaspert et al. [45] in their article, the one provided is similar but has been updated concerning developing trends.

In particular, developing software capable of simulating and/or analysing measured parameters is a crucial aspect of smart retrofitting. The analysis of the 28 articles (listed in Table 5) shows a need to focus on smart retrofit actions to develop, enhance or expand the software side: 27 articles underline the importance of the software side, while only 24 describe the hardware side.

Table 5. Hardware–software implementations.

Reference	Software Implementation	Hardware Implementation	DT
[51]	-	Mechanical devices to improve the performance of the old machine	
[14]	Anomaly detection system	Integration of smart sensors into the system	
[2]	Digital Twin, anomaly detection system and prediction tool	Integration of smart sensors into the system	•
[10]	Implementation of internet connections for remote access and connection to the cloud system	Integration of hardware devices for connectivity	
[49]	Augmented reality applications, condition-based maintenance, predictive maintenance, condition monitoring, energy management, Digital Twin	Integration of smart sensors and communication protocols	•
[8]	Development of neural networks for quality detection	Raspberry Pi and camera integration	
[3]	Development of user interface, data acquisition and processing systems	Integration of smart sensors	
[42]	Development of an augmented reality module	Integration of connected glasses for augmented reality	
[43]	Control and monitoring program	Integration of Raspberry Pi	
[44]	Remote control system with OPC UA server	Sensor and Raspberry Pi	
[4]	Human–machine interface, numerical control kernel software, PLC software	Integration of machine control unit	
[52]	Mixed-reality software	Mixed-reality visor	
[9]	Convolutional network based on Visual Geometry Group	Integration of Raspberry Pi	
[16]	Deep learning for face detection		
[38]	Data monitoring software	Integration of smart sensors	
[13]	Digital Twin, machine learning algorithms and user interface development	Smart sensor and tablet integration	•
[17]	Imaging software and OPC UA software	Camera and PLC (programmable logic controller) integration	
[7]	A supervised machine learning algorithm with lumped parameter simulations	Smart sensor integration	
[35]	Implementation of a Digital Twin, genetic algorithms and artificial neural networks	-	•
[37]	Implementation of Digital Twin	Zenerit system integration	•
[41]	Use of OPC UA software	Integration of devices such as Arduino or Raspberry PI	
[47]	Development of a mobile application for remote access	-	
[48]	Digital Twin and artificial neural networks algorithm	-	•
[22]	A machine learning algorithm for decision making	-	•
[53,54]	Digital Twin, machine learning algorithms, HMI, MySQL, Android app	Arduino, camera, smart sensors	•
[22,55]	Digital Twin, WAGO software, machine learning algorithm	Controller and I/O modules, smart sensors, LVDT, WAGO node	•
[55]	Digital Twin, open-source simulation tools, MySQL, PostgreSQL, edge computing, Node-RED	Raspberry Pi, Arduino, smart sensors, DAQ units,	•
[56]	Digital Twin, HMI, virtual model, OPC UA software, machine learning algorithm, Web access platform	Sensors, Raspberry Pi, camera, PLC	•

Of course, to develop the software side, it is necessary to obtain information from the plants, machinery and systems. Thus, it is still a requirement to retrofit at the hardware level.

Table 5 also shows that, in several cases, a Digital Twin was used and implemented to retrofit old machines. This is justified because a Digital Twin allows several retrofit actions to be performed simultaneously with a single platform: safety criteria, maintainability, monitoring, fault detection and analysis, and much more, can be improved [2]. A Digital Twin is an exceptional tool because it perfectly combines the transfer of information between its physical and virtual counterparts. When the physical object is reproduced in the virtual system, changes to the virtual system can affect it. The bi-directional transfer or allocation of data between the physical resources and the digital counterpart, including quantitative and qualitative data, stored data and real-time bi-directional data, is an aspect that characterises DTs, in addition to the fact that they contain a virtual representation of physical resources [53].

Therefore, the following section reports the main software-level and hardware-level actions of smart retrofitting and the benefits they bring.

3. Implementation of Smart Retrofitting

Given the definition of smart retrofitting, it is possible to search the literature for reasons why to apply a retrofit or smart retrofit action, and for solutions and benefits to be found.

First, it is good to define what steps need to be taken to properly implement retrofit/smart retrofit actions.

Tantscher et al. [49] propose a holistic methodology for implementing digital retrofitting from an Industry 4.0 perspective. They identify four superordinate aspects that form the frame of the process: strategy, interdisciplinarity, change management and lean management. A direct relationship relates the four superordinate aspects and the operational process. The procedure includes the following steps:

- IIoT Use Case: optimising asset maintenance, increasing the efficiency of assembling processes and improving machine monitoring.
- State analysis: an analysis of the current state.
- Action planning: specific actions depend on individual requirements and the specific use case.
- Implementation: installation of all hardware and software components and virtualisation of physical objects is necessary.
- IIoT integration: platforms for data visualisation and analytics.
- Verification: if the correct data are measured/transmitted correctly.
- Validation: compliance with the predefined usage targets is checked.
- Standardisation.

Following the eight steps makes it possible to properly evaluate and carry out a machine/plant retrofit. Specifically, with the definition of an IIoT use case, the company outlines the target to upgrade the actual state of the system. Often, implemented use cases aim to optimise the maintenance of assets (condition-based maintenance, predictive maintenance), increase the efficiency of assembly processes (augmented reality applications) and improve machine monitoring (condition monitoring, energy management, Digital Twin) [49]. This article realised the smart retrofitting action by implementing a DT. This can be simplified into four steps for legacy system renovation. An article by Stock and Seliger [5] discusses a retrofit action on a legacy system in four steps:

- situation analysis;
- definition of the monitoring strategy;
- data processing;
- implementation of the equipment in a CPS.

For a milling machine retrofit, a Beckhoff PLC converts analogue signals from the acceleration sensor into digital signals for subsequent data processing. The data processing takes place. A human–machine interface realises data visualisation. This milling machine can now be implemented in a CPS. In connection with an intelligent product, the retrofitted machine can program the material flow in a decentralised manner. It can react automatically to machine failures, for example, by informing the responsible worker. Ilari et al. [38] use a similar implementation methodology to the one above. They conducted a study comparing retrofitting dated machines with the purchase of new ones, focusing on the sustainability aspect (economic, social and environmental). The framework was implemented in five steps: “objectives analysis,” “market analysis,” “retrofitting analysis,” “collecting information” and “selection of the best solution through the AHP”. The evaluations are applied to the case of a drill press. The hardware and software technologies are simple and inexpensive, allowing drill management through a smartphone application. In addition, retrofitted machines demonstrate a significant sustainability advantage over new machines.

3.1. New Drivers for Retrofitting/Smart Retrofitting

Retrofit brings innovation not only to the machine level; sometimes it can be seen as adapting to new market demands and improving working conditions.

Bakir [11] and Ehrlich [12] et al. see retrofit as an activity for old machines and an opportunity to make new machines more versatile. This characteristic is necessary because the way of doing business is changing because of the quantities being produced, e-commerce and online sites revolutionised business models and customer demand for customisable products. This aspect is crucial when it comes to small and medium-sized enterprises, which encompass people and machines not related to the Industry 4.0 paradigm, generally present a “climate of distrust” in digitisation, cannot bear the onerous costs and long lead times of the eventual replacement of an entire production asset and sometimes lack know-how. On the other hand, sometimes retrofit actions can be the first step toward Industry 4.0 for a small and medium-sized enterprise. Leona Niemeyer et al. [3] report a simple and inexpensive way to bring companies (especially small and medium enterprises) into compliance with Industry 4.0 standards. They show a simple system integrating smart sensors, IIoT platforms like Thingworx and Kepware and condition monitoring software. These tools enable SMEs to develop new business models and be more competitive for a low investment.

Similarly, Keshav Kolla et al. [43] report an example of retrofitting that can be applied to SMEs because they have limited resources and implementation time. In this case, a system is implemented (experimentally) to integrate new functions within old machinery. In fact, at the physical level, new sensors and smart devices are installed, which are then connected to PLCs and/or microcontrollers (e.g., Raspberry Pi). Communication is possible by following the UPC UA/ethernet protocols, which communicate with the IIoT layer. This, in turn, is connected with the cyber layer, where the databases and monitoring/analysis systems (implemented in MATLAB, Grafna, InfluxDB) are located.

A case study, reported by Burresi et al. [17], concerns Fonderia Gelli, a steel mill producing industrial cast iron and steel components. The first step in the configuration is to interface with the Samsung S7 PLC system to enable a connection via the OPC standard. A proprietary Siemens OPC-DA server runs on a Windows machine—a UDOOx86 board—allowing a custom Python application to obtain data from the PLC and forward them to remote services for data analysis. An IP camera is also connected to the gateway to allow external services to access the video stream. It is supported by imaging software and computer vision (CV) algorithms. This makes it possible to visualise part defects, stop production and report anomalies to the operator, who can take corrective action based on the information reported on the user dashboard. An article by Generosi et al. [16] also discusses a retrofit action for a worker identification system to prevent workplace accidents and improve worker conditions. The hardware retrofit uses Raspberry Pi 4, a touchscreen display, an embedded webcam and LEDs.

New Drivers for Retrofitting/Smart Retrofitting: Digital Twin and "Digital Triplet" Solutions

As mentioned, different drivers require smart retrofit action on the old assets. Sometimes the necessity to introduce the I4.0 paradigm in the system with limited investment makes it possible to also apply smart retrofit actions to new machines that are not 4.0.

In many articles, the smart retrofit solution is the realisation of the system's Digital Twin (or its extension: "digital triplet"). This section reports the main applications found in the literature for the different drivers.

As mentioned above, SMEs often do not have the time, money or knowledge to completely change their business assets. At the same time, they are faced with the need to introduce the Industry 4.0 paradigm. To realise this step, they need a solution such as smart retrofitting.

In an article written by Mazzuto et al. [50], these factors are evaluated, and the implementation of a Digital Twin and machine learning algorithms are identified as the solution; in this way, plant failures can be predicted and detected. This approach requires limited investment and reasonable time (suitable for SMEs because it uses "economic" algorithms, software and a connected sensor for control and monitoring), enables innovation, fits into I4.0 and allows an old plant to be transformed into a smart plant. In addition, the plant can quickly communicate with operators to increase their safety and aid in their decision-making.

Ruppert T. et al. [55] also point out in their article that manufacturing industries, especially SMEs, often lack the knowledge and resources to develop I4.0 solutions. In these situations, a smart retrofit can provide a quick and cost-effective way to improve productivity and competitiveness. For these reasons, they propose Digital Twins of several old machines to retrofit them and extend their useful life.

A case proposed by Hassan could be a retrofit solution applicable in the context of an SME: the article shows the construction of a DT of a drilling machine. In addition, this article talks about the Digital Twin and "digital triplet" implementation, which will be discussed in more detail in Section 3.2.1. However, the solution requires the use of simple and inexpensive devices such as Arduino, anomaly detection algorithms, a camera for operator recognition and other cheap and easy-to-use technologies adequate for an SME. Furthermore, the application of a "digital triplet" can also answer another driver: the possibility of reusing the old asset and valuing the experience of workers can create a climate of "acceptance" towards adopting Industry 4.0 technologies and put the workers in a "central position" in the company.

Another aspect is sustainability, particularly environmental sustainability. In order to be able to reuse a machine, it is possible to apply retrofit actions through the construction of a DT and a "digital triplet". Burresi et al. [17] report an example that used the same PLC (Siemens PLC S7), Raspberry Pi, camera and OPC UA standard of the article reported in the section before by Michael M. et al. [56]. Contrary to the previous case, this article shows the implementation of the "digital triplet" to carry out a retrofit of an outdated machine. A Digital Twin, Raspberry Pi, OPC communication server, Web platform and camera extend the life and functionality of a three-floor elevator.

Ermini et al. [13] analyse the relationship between man and machine in the industrial sector (human-centred retrofitting) and how introducing data collection devices, sensors, Digital Twin, PLC, and machine learning algorithms represents an opportunity to redesign this relationship in production processes. The proposed DT implementation solution aims to allow the plant to increase efficiency, decrease machinery faults and produce rapid and low-cost technical improvements. This type of implementation enables environmental sustainability and social sustainability for workers.

Mazzuto [50] and Bevilacqua [57] propose similar considerations and developments: the approaches enable predictive maintenance applications. In this regard, the proposed Digital Twin can create virtual modelling of maintenance processes, thus preventing high-risk events for operators.

3.2. Technologies for Retrofitting

Some technologies for implementing retrofits are mentioned in the previous sections. Next, this section analyses those found in the literature: IIoT, cloud, communication architectures, machine learning and augmented reality. Finally, a specific section will focus on Digital Twins and "digital triplets" that are the most utilised.

The importance of desktop/Web applications and human–machine interfaces is emphasised by García et al. [14]. In this article, there is a modular infrastructure that is composed of different microservices to store and process data. All information from the various tiers is connected using Web APIs. There are three parts: a portable IIoT infrastructure with non-intrusive sensors, heterogeneous data streams to the edge tier and software interfaces; a cloud-based service architecture, hosting a common information connectivity layer and data models to the cloud tier; and end-user human–machine interface (HMI) management, with interactive human–machine software tools and asset health condition-based strategies providing knowledge models to the business tier. The DFM (data flow management) module contains information about system configuration and status, real-time data, data analytics, augmented contents and dashboards. This module is valid for anomaly detection analysis and advanced system monitoring. The results of these analyses and all data can be displayed in real-time on the operator's device. The technology implemented in an article by Kumar et al. [9] proposes to retrofit an analogue water meter. Such a study could be helpful and re-applicable to industrial systems with similar devices. An external structure is built to be mounted on the analogue meter with an LED, Raspberry Pi and a router for internet connection and data transmission. The software component is added to the hardware implementation using a deep learning algorithm for image recognition. The algorithm uses a convolutional neural network based on the Visual Geometry Group (VGG) architecture. The system allows real-time and remote readings of meter data.

Panda et al. [36] apply a retrofit regarding hardware, communication and the cloud. They implement a device layer and integration layer. The first layer comprises one or more field devices attached to sensor nodes. The second layer of the architecture consists of a physical device capable of communicating with the sensor nodes that will provide the value of process parameters. OPC UA is identified as the ideal candidate for middleware communication protocols as it allows for platform-independent, service-oriented architecture with a standardised information model. AWS Greengrass facilitates interaction between Raspberry Pi and the AWS IoT core. Further, the acquired data can be analysed in AWS IoT analytics and used for forecast learning and predictive analysis. For a food company, the quality of ingredients can be determined and enhanced by adding these features to reduce waste, resulting in cost-effectiveness.

All these techniques for secure transmission, visualisation and storage of data related to retrofitting can also be applied when developing a DT (Section 3.2.1), as mentioned in Hassan Alimam's article [53].

Chang, in his article [58], examines a crucial aspect that characterises Industry 4.0: IIoT and security issues in data transmission. The report highlights how retrofitting activities can also focus on implementing more secure connections and integrating security systems.

Arjoni et al. [39] report examples of retrofits of different devices. There are also laptops for plant interaction, virtualisation and computational vision systems, entry/exit/disposal benches and RFID. In fact, in these cases, they use devices such as Arduino Uno, Raspberry Pi 3, RFID (and related readers), communication protocols such as OPC UA and UPC and software such as Labview and Tecnomatix. They conclude that the retrofit strategies have a good cost-benefit ratio, permitting old equipment to be used as elements of advanced manufacturing with little programming and mechanical adaptation effort. Haskamp et al. [31] aim for a Flexible Manufacturing System by exploiting PLC, sensors, four different cameras, RFID, UPC UA communication protocols and RAMI 4.0.

In addition, a digital interface has been developed that allows the operator to check the system status, real-time data, historical data and system control. Also used is a dataFEED OPC Suite that allows writing/reading to PLCs and Azura IoT Edge to run programs and cloud services. Kofi Atta Nsiah et al. [26] describe how the NIKI4.0 Toolkit is implemented and how it can enable process monitoring and real-time visualisation. In addition, OPC UA securely allows data exchange, and MySQL allows the storing of historical data. Finally, Oks et al. [8] discuss the retrofit activity to be implemented on a PID4CPS (Portable Industrial Demonstrator for Cyber-Physical Systems). They equipped the PID4CPS with a camera, a Raspberry Pi system, UPC UA communication protocols, imaging software and neural networks. All combine to return a system capable of autonomously detecting the degree of shelf filling.

The use of neural networks, machine learning algorithms and artificial intelligence is also applied in the cases mentioned below.

Strauß et al. [28] focus on low-cost retrofits, especially concerning sensors (e.g., RFID). Arduino, Raspberry Pi and Banana Pi are mentioned as embedded systems that can interface with different types of sensors and cloud services. The cloud service can be implemented with Microsoft Azur IoT Device SDK. Already known architectures such as RAMI, ARM or IIRA are also reported for IIoT architecture implementation. Again, Azure Cloud is mentioned in the part concerning the cloud platform.

A cloud data collection system then provides the input to the "data processing, analytics and management" systems in which storage, stream processors, analytics and machine learning, business integration connectors and gateway components are present that then connect with the "presentation and business connectivity" layer for integrating personal mobile devices and business systems. Etz et al. (2020) also reported similar considerations and implementations [44] in their article. This paper shows an approach to enable predictive maintenance for production machines by retrofitting using low-cost sensors, an IIoT architecture and machine learning. The paper describes how low-cost hardware and software can be used to build a CPS for implementing condition monitoring and machine learning. A recommendation of this case study is to start by using a semi-supervised model to detect and store anomalous data. After collecting sufficient failure data, the clustering method can be trained and inserted into the predictive maintenance process after the anomaly detection model, thereby only clustering the anomalous data marked by the anomaly detection model. With input from domain experts, the results would lead to a dataset of detected anomalies that can be classified and optimally used for the supervised classification of faults.

The use of machine learning algorithms can be employed to solve common retrofit-related problems. In their article, Pupăză et al. [7] analyse a prevalent problem when performing retrofits or smart retrofits: overheating of systems. Overheating can lead to system damage and incorrect evaluations of acquired data. Then control logic and machine learning algorithms based on deep learning neural networks are implemented. The acquired data are then processed and graphed onto a model. This application makes it possible to extend the life of electronic systems, reducing overheating and subsequent failures.

Since there are many cases in the literature where the Digital Twin represents a retrofitting solution, the following is a section on smart retrofit actions through DT.

3.2.1. Technologies for Retrofitting: Digital Twin and "Digital Triplet"

IIoT, cloud, communication architectures, machine learning and augmented reality are utilised in the "digital triplet", where, from the interaction of the Digital Twin with human knowledge, it is possible to create more immersive virtual spaces, more user-friendly interfaces and simulative environments in which one can insert avatars of one's operator and work safely. These possibilities enable various aspects such as environmental, social and economic sustainability, greater security in the training and work of the worker and more. The digital triplet of the four-level hierarchy was used for the retrofit of a drilling machine in the study reported by Alimam Hassan et al. [53]. The article highlights how the "digital triplet" and DT are intelligent tools for the retrofit of older machines at low cost. The three interactive components of the digital systems are the digital master, which is the anticipated state of the system's validity and adjustment by devoting (machine) learning;

the Digital Twin, which is the duplication of the system where mixed data, information, models, methods, tools and techniques are present; and the digital prototype, which is the envisaged state of the emulated system. The advanced stages of the traditional Digital Twin paradigm are the intelligent activities layer and the master component of the digital system. In order to create an innovative study of the numerous tactics, the “digital triplet” concept, which was created as an implication of intelligent evolution, encourages the fusion of the actual, virtual and intelligent activity worlds with human awareness.

Thus, the “digital triplet” requires a four-level aggregate of Digital Twins. The hierarchy was created using the four levels of complex advanced decision-making, using machine learning based on human intelligence and creativity, the control of physical system behaviour prediction and emulation, maturity in terms of iterative observation of actual physical system behaviour using real-time data and a level for visualising and simulating virtual features. The hierarchy clarified the intelligent actions based on transforming and extracting the human awareness required to advance the digital triplet paradigm’s apex, improving convergence and facilitating the exchange of data and information across cyberspace, physical space and people.

The digital triplet decreases financial risk while improving the viability, security and resilience of smart retrofitting. Through smart actions, the Digital Twin enhances human–machine integration and skill transformation. The evaluation showed that the digital triple hierarchy could be retrofitted to user-preferred intelligent solutions, utilising the creativity of human experts working with intelligent Digital Twins and reducing the complexity of the paradigm through interaction between various levels of the digital triplet and human awareness, as well as by clarifying the functionality of pertinent information for each Digital Twin across all levels. All are applied to an outdated drilling machine on which new sensors, devices and cameras are applied, and on which a Digital Twin is built. The control is realised with an inverter (Schneider electric Altivar machine ATV320). At the same time, the data transmission is done with an Arduino Mega with an ethernet shield for control and data transmission with an ethernet protocol. To collect vibration data, a vibration sensor with Arduino Nano 33 IoT and wireless transmission protocol was installed in the machine. A node-based JavaScrip server enables real-time data transmission between the physical and digital parts. MySQL was utilised for data transfer and as a repository for digital data produced by the camera and IoT subsystem. AI-based decision-making and anomaly detection systems were built to analyse the behaviour of vibrations during machine operation. The intuitive human–machine interface and the Android application for identification were developed and connected to the system.

In their article, B. Ralph et al. [22] report on the construction of a six-level digitisation architecture that can be integrated into a CPS to perform a smart retrofit on older machines and transform them into a low-cost and user-friendly system using machine learning algorithms. Building a DT and applying smart sensors and controllers make it possible to access condition, process and management data and realise a perfect low-cost, user-centred CPS.

Mazzuto et al. [59] also used artificial neural networks (ANNs), swarm intelligence algorithms and a smart sensor plant to make a Digital Twin (DT) and monitor the operating status of a multiphase flow ejector. These algorithms allow for analysing the ejector’s operation according to the set conditions and evaluating malfunctions.

Many other authors see the Digital Twin as an effective retrofit solution. For example, an article by Hegedus [27] shifts the focus to the supply chain and warehouse, analysing the relocation and storage of raw materials, work-in-process inventories and even the shipping of finished products. The systems used are real-time locating systems (RTLS), the indoor positioning system (IPS) from AITIA, ultra-wide band (UWB) ranging technology, Bluetooth Low Energy (BLE), radio frequency identification (RFID), Arrowhead SOA systems and a local cloud. These systems solve many problems regarding workstation automation, tracking of the entire supply chain, the possibility of creating a Digital Twin for manufacturing production in the best possible way and application within existing facilities without disrupting machinery and production. Moreover, in this way, it is also possible to exchange helpful information with other systems.

In their article, Di Carlo, Mazzuto, Bevilacqua and Ciarapica et al. [2] set goals to improve working conditions, achieve better quality processes, achieve better communication and collaboration, improve productivity, efficiency, flexibility and agility and reduce costs. They seek to implement a system capable of anomaly detection to achieve most of these goals. The anomaly detection software is implemented through data from a Digital Twin. In fact, as a first step, a DT is implemented through a supervised approach. DT allows the behaviour of the real plant to be replicated in a digital environment. Then, knowing the standard behaviour under various conditions, it is possible to evaluate the abnormal operating condition (with proper tolerances) and report it. The Digital Twin then makes the digital counterpart of an existing physical system. A description of how a Digital Twin can be developed is provided by Bevilacqua et al. [57]. This article describes five implementation steps (development of the risk assessment plan, development of the communication and control system, development of Digital Twin tools, tool integration within a Digital Twin perspective, models and platform validation) by which it is possible to enable technicians to make repair decisions based on data and predictions; it provides a tool with high added value for evaluation of risks and helping business leaders in decision-making activities, not only from an economic but also from an organisational point of view.

It may be more useful to leverage or combine augmented reality technologies. For example, in a case described by Mazzuto et al. [54], more innovative technologies, such as IIoT (combined with connections, HMI and cloud systems), Digital Twin and augmented reality, are implemented.

Mourtzis et al. [42] propose a solution designed to work with Microsoft HoloLens that integrates a machine learning algorithm. They define three levels for the implementation of the framework. The first layer includes the back-end application, which contains the infrastructure, the communication protocols used and an online database for handling all the data needed for the framework operation (the Cloud SQL database was used for cloud information management). The second layer consists of the front-end application used by the users. Finally, the third layer identified is the augmented reality (AR) module, which combines all the pertinent data to visualise the digital models in the user's physical environment. The main benefits found were low-cost implementation, extended machine life cycles and implementation of AR systems for improved performance.

Hassan Al-Maeeni et al. [4] also implemented the same technologies for the same purposes but in a real manufacturing plant.

A similar structure is presented by Mazzuto et al. [54]. The article describes how a pair of smart glasses (Vuzix Blade) can guide an operator through a facility and its status. Specifically, a notification is shown on the lens that provides an alert about the status of an element of a plant and the actions to be taken. Additionally, Settimi et al. [52] talk about a retrofit applied to a machining bench where a drill is used to drill holes. In addition, using a handheld IR-based scanner (FARO® Frestyle2), the timber stock (in batches) was digitised to obtain digital replicas of physical objects. Integrating the drill retrofit within the technologies installed on the wood pallets makes it possible to achieve automated workflow flexibility and simultaneously provide an asset digitisation opportunity to small companies with low-level entry technology by leveraging the already present know-how and pre-existing manual tools.

In addition, in the context of Digital Twin, the use of Industry 4.0 reference architectures such as RAMI 4.0, NIKI 4.0 and OPC/OPC UA is reported on. Lins et Oliveira [10] propose a method for retrofitting within manufacturing plants a CPPS (cyber-physical production system). The entire process is based on Reference Architectural Model for Industry 4.0 (RAMI 4.0). First, the infrastructure of the company is evaluated and an attempt is made to implement an embedded board component that can support various connections and IoT device components. After that, they move to the communication level, where they must evaluate the network component and protocols to allow them to adapt to the

OPC/OPC-C/SDN-C communication standards. Last but not least, functional elements of the CPPS are implemented: a database component; a remote access component; a Web service component; a monitoring component; and a cloud component. This paper applies this structure (NIKI 4.0) to a robot that significantly improves energy efficiency and control. However, it could also be applied to a DT, which is itself a smart retrofitting solution.

3.3. Advantages of Smart Retrofitting

Many benefits have already been mentioned above or can be inferred from retrofit applications. However, it is possible to explore them further in this section by answering an additional question: why should a company adopt retrofitting or smart retrofitting solutions?

The previous section discusses different aspects that drive a company, not necessarily an SME, to undertake retrofit actions. Regarding new business models, it has been shown that there is a growing trend to produce more customised products; such products have, in principle, the same characteristics, but they can vary in secondary aesthetic features (customisations). Sometimes it is costly for a company to purchase different machinery to enable customisation. On the other hand, not having this option makes the company less competitive. Therefore, one can think of applying a retrofit or smart retrofit activity to new machines as well. Additional mechanical devices with related control systems and software could be integrated (imaging software and connected cameras) for smooth production management of the same essential product, with different customisations but the same quality.

Moreover, "new business models" also mean the quantity produced. In this regard, being able to sensitise a machine or an entire system, build a Digital Twin or simply monitor the performance of a machine/system allows us to understand what the critical points are and the areas where there is a need for maintenance, and to properly manage resources (both material and energy). It is precisely for this reason that it is possible to say that the Digital Twin appears to be one of the most cost-effective smart retrofit solutions, as it allows for the integration of anomaly detection systems, simulation systems and communication systems with other Industry 4.0 devices within old machinery.

Moreover, among the new business models, the recent trend of selling a service instead of a physical product should be noted. Technology is advancing day by day, and it is difficult for those who buy machinery to be able to keep up. Generally, a company buys machinery carefully, planning depreciation and machine usage time. Therefore, it might be a good business strategy to provide, along with machinery, a series of "upgrades" based on retrofit actions. All of this should also be conducted with a view to savings and sustainability. Retrofitting enables social sustainability in the sense of the well-being of the worker who is accustomed to working with old machinery: if old machinery is integrated with smart devices, the operator will be able to gain benefits in terms of decision-making, equipment monitoring and safety, but without having to disrupt his knowledge and skills. In particular, in the case of "digital triplet" integration as a smart retrofit action, the knowledge of the operator and engineers is crucial for constructing technologically advanced and high-performance systems.

Retrofitting also refers to economic sustainability: it brings benefits on the production side because new production, quality and resource management functions can be enabled, but it also brings innovation on the implementation side of these technologies. Ilari shows that retrofit actions cost far less than purchasing a new machine [35–38]. Often, the issues of efficiency and time-to-market in developing, experimenting, testing and deploying new products are the preserve of large companies. However, this scenario, thanks partly to the cloud, is changing. At this time, detailed analysis of risks, knowledge of possible threats and the ability to seize all simulation development opportunities with the utmost precision appear increasingly within reach of the SME world [60]. Retrofitting also enables environmental sustainability because there is no need to dispose of old machinery to purchase new machinery: technology is implemented directly all over the dated machinery. In addition, retrofitting encourages environmental sustainability, especially with the construction of

Digital Twins or simulative spaces: they digitally simulate system operation and performance without wasting resources and time. Therefore, applying retrofit or smart retrofit actions on a machine or system can bring many benefits, especially since having smart sensors, software systems and DT systems enables the extension of various functionalities without requiring great economic or time efforts. The capacity to create from this retrofit action a product or, better yet, a service could be the key for many companies to free themselves from building a physical asset in favour of a more digital one.

4. Conclusions

This paper analyses retrofitting and smart retrofitting to adapt systems to the Industry 4.0 paradigm. As a result of the literature review, smart retrofitting is defined as an innovation of legacy machines, introducing sensors capable of sending data related to production and/or machinery status. These data are then reprocessed to provide helpful information for production, maintenance, product and service quality.

The analysis showed several benefits of smart retrofit actions in the industrial sector. First of all, this activity is sustainable in several respects as it allows the reuse of machinery. Environmental and economic sustainability aspects are evident, and it is essential to develop software capable of controlling, simulating or performing analysis concerning all aspects of production. In most cases, retrofitting/smart retrofitting targets dated systems that need to be integrated within both the software and hardware sides. This article measures the importance of developing the software side in smart retrofitting. Sometimes smart retrofitting can be used in "modern" systems to adapt to new market demands and new business models and improve working conditions and production (in terms of quality, costs, waste, etc.). In these terms, the construction of a DT has proven to be highly advantageous as it allows monitoring, simulation, analysis and optimisation of a process/product/system by simply accessing a single interface. Smart retrofitting also allows small and medium-sized enterprises to approach Industry 4.0 without making significant investments, saving time and disrupting the business asset. This aspect also ensures economic, social and environmental sustainability. In general, companies that want to improve the sustainability, effectiveness and safety of their equipment can gain a lot from smart retrofitting. This strategy can contribute to extending the life of current equipment, cutting costs and improving the general performance of equipment, making them a good investment for many companies.

In many cases, it is necessary to implement hardware devices, such as sensors, PLC and Arduino, and a software counterpart to collect the data. Therefore, appropriate and secure communication protocols are needed. In this regard, it is also essential to develop a cloud system. Many cloud architectures can already be implemented (RAMI 4.0, OPC UA, NIKI 4.0, etc.). In some articles, the Digital Twin is registered as a system for accomplishing most of the actions mentioned before and achieving an effective smart retrofit action. In addition, the Digital Twin concept can be extended with the "digital triple" paradigm, which integrates the knowledge of engineers and operators with the traditional DT idea. This integration makes it more possible to integrate new, more efficient technologies into an old system, realising the various aspects of sustainability to a greater effect. For these reasons, it is possible to say that the "digital triplet" and DT constitute two very effective systems for carrying out smart retrofit actions on old systems and plants.

On the other hand, one of the most significant limitations of smart retrofitting is that not all equipment is compatible with this approach. Some equipment may be too old or specialised to be upgraded in this way, limiting the potential for this approach to be widely applied. In addition, implementing retrofitting often demands specialised technical competence. This aspect might be challenging for businesses that lack the requisite internal talent because they might need to employ external experts or contractors to do the work. However, whether retrofit actions can be applied to the machine and exploited to its full potential, the information obtained (e.g., from the introduction of smart sensors) can create added value when reprocessed with a view to control, predictive maintenance, anomaly detection and real-time monitoring. Furthermore, this analysis can report faults to the operator, help him in decision-making and improve his working conditions and safety.

As companies and researchers continue to look for new ways to increase the efficiency and sustainability of existing equipment, there are many potential future developments in smart retrofitting. As new technologies emerge, new opportunities for smart retrofits also arise. The development of ever more advanced machine learning algorithms and the increasing use of neural networks could help companies better understand where business inefficiencies are and lead to automatic optimisation of equipment performance. Developing new PLCs or compact industrial PCs can also foster the development of more advanced and powerful SR solutions. In addition, developing and increasing the use of the digital triplet paradigm can bring enormous benefits and innovation to old machines. It extends the traditional concept of the Digital Twin by incorporating the experience of workers, machine learning and decision-making algorithms, and from this, it is possible to extract only the essential and useful information with which to analyse, improve and perform the new solution for the old machine. Moreover, the application of the "digital triplet" projects the system towards what can be defined as Industry 5.0, which succeeds in putting man at the centre of the business environment (a goal that Industry 4.0 also sets itself without fully achieving). The use of operators' knowledge becomes crucial and a precious resource to be supplemented with knowledge from the digital world.

In addition, the circular economy is an emerging framework for sustainability that emphasises the importance of reducing waste and maximising the value of existing resources. Smart retrofitting could be an essential component of the circular economy, as it helps extend existing equipment's life and reduces the need to produce new equipment. As things stand, however, a smart retrofit action must ensure that the characteristics of the certified old machine are not changed; otherwise, it is necessary to recertify the machine. As smart retrofitting becomes a more widely used strategy, more regulations will be drawn. There are already certifications for retrofitting in Europe, but of course, they should be updated according to applicable new technologies. These certifications can support ensuring equipment performance and safety while also providing firms and customers with assurances regarding the quality of retrofitted equipment.

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