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EXECUTIVE SUMMARY OF THE THESIS

Industrial Internet of Thins: state-of-the-art and directions of future development

TESI MAGISTRALE IN MANAGEMENT ENGINEERING – INGEGNERIA GESTIONALE

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Introduction

For a number of years now, we have been witnessing a revolution in the world production system, which precisely goes by the name of the Fourth Industrial Revolution. The industrial world is trying, in increasing measures, to take advantage of the enormous technological progress that has developed in recent years. Resuming the theme of the Third Industrial Revolution, with which industrial automation began to be exploited for the first time in history through the use of computers within industry, we are now aiming for the massive use of digital technologies that can create enormous value through the generation of data. From these, any company can potentially derive a gigantic amount of information that, if well used, will contribute significantly to the creation of competitive advantage. These are some of the factors that characterize Industry 4.0, a term that was first used during the Hannover Fair in Germany in 2011.

PNRR

In this context, the Italian government, recognizing the fundamental importance of promoting the technological development of the companies in its territory, has included the theme of digitization as a protagonist of the Piano Nazionale Ripresa e Resilienza, through the new Piano Nazionale Transizione 4.0 (subsequent to the Piano Nazionale Industria 4.0 developed earlier in 2017). With the new plan, scheduled investments have reached 24.3 billion by 2022 and include, among other things, an increase in the tax credit for R&D-related expenses (from 12 percent to 20 percent) and the transformation of the super and hyper depreciation for innovative 4.0 assets, into a tax credit.

Industrial Internet of Things

In the context of Industry 4.0, one of the technologies that has made a major contribution to the digitization of industry is definitely the Internet of Things (IoT). This strong influence came from its ability to integrate the virtual world with the real world, taking advantage of the massive use of sensors (inside machineries, warehouses, water

networks, products and many others), which allow a huge amount of data to be collected and enable all the constituent parts of the factory (operators, machinery, software...), to talk to each other in a smart way. In addition, another great advantage is its versatility. In fact, IoT can be leveraged in numerous applications including smart factory, smart metering, smart home, smart logistics, smart car, smart building, smart agriculture, smart city, and smart asset management.

Within the wide world of IoT, Industrial IoT (that is the main topic around which the entire thesis revolves) represents an important part. As the name suggests, Industrial IoT consists of applying all the principles and technologies of IoT in the industrial environment. The focus has been placed particularly on three fields of application, which appear to be those most developed in the Industrial IoT field:

Smart Factory: The smart factory concept is based on the use of digital technologies that make it possible to integrate current manufacturing processes. It is based on the use of sensors to monitor machinery and products in the shopfloor. This provides numerous advantages in terms of management such as real-time visibility on the correct status of the machinery, the possibility of implementing preventive maintenance logic (or even predictive maintenance), up to situations in which it is the machinery that autonomously (by analyzing some of the data collected), is able to make decisions regarding its management. As a result, there will be a significant impact on business performance in terms of production, quality and energy consumption.

Smart Logistics & Supply Chain: by leveraging IoT in the supply chain, companies can gain tremendous benefits: increased visibility, increased security (of data and products), information from other value chain participants that is more reliable and easier to share, optimizing routes for transporting products, and streamlining internal company movements. All of these benefits are made possible through the modernization of the current supply chain into data-driven supply chains, which allows to identify in real-time the location of every object in it, making its optimization possible.

Smart Lifecycle: represents the management of the entire product lifecycle (from design to disposal stages), within a digital and interconnected context. It enables valuable information that can be used to optimize the product itself. For example, companies, through IoT, could greatly improve the development process of new products by analyzing historical data of previous versions. Or they could improve the product (in terms of performance/service offerings) by analyzing how customers are using it.

Although there are countless potential benefits that companies would be able to gain from using IoT, there are still different barriers and weaknesses that hinder the large-scale deployment of this technology. Among the most important ones there are cybersecurity issues, the need to adapt and own infrastructure and invest in new ones to foster integration between IT and OT, the lack of a common standard that would allow easy interconnection between IoT systems from different industries, the large energy consumption due to the permanent activation of the various IoT technologies, and the difficulty in exploiting the maximum potential from the large amounts of data collected.

Research objectives

The primary objective of the research is to deepen the state of diffusion of this technology in Italy and abroad. The question I will ask during my thesis work is, therefore, the following: *Which is the state-of-the-art of Industrial Internet of Things technology?* In addition, I will focus on the analysis of the future trends that will characterize the next years of IoT evolution. Specifically, I want to understand which are the proposal of the most innovative start-up, and therefore, which are the proposals that will likely improve the degree of diffusion and effectiveness of IoT technology. The main questions that have been faced are: *Which are the most influential trends that are changing the world of IIoT? How is the theme of environmental sustainability impacting on IIoT development? In what measure are companies focusing on it with their IoT solutions?*

Methodologies

Different types of sources were used throughout the entire thesis work.

Literature review: in order to develop the first chapter an analysis of the literature was made. This

allowed me to understand and report the fundamental concepts of this paradigm. To do this, the main articles on the subject were analyzed using the search engines of Google Scholar, Scopus and Science Direct. Being the IoT a technology that has witnessed (and is still witnessing) a great development, it has been chosen to select only the most recent sources, avoiding articles that discuss the topic in a context too different from the current one.

Primary sources: the thesis develops around the survey conducted in collaboration with the Osservatorio Internet of Things. Through the survey we investigated the current state of adoption of IoT solutions within the companies interviewed. The questionnaire comprehend 24 questions and it can be consulted in the Appendix.

Secondary sources: in order to analyze the degree of diffusion of IoT in Italy and in the world, one of the objectives of the thesis is to map the projects that have been implemented in recent years. I contribute to expand a database of IoT projects provided by Osservatorio IoT using the following sources: IoT technology supplier sites, specialized websites in the world of digitalization and corporate sites.

Finally, it has been exploited the website "Crunchbase" to conduct a research of the most innovative start-ups operating in the IoT. Here a total of 43 start-ups have been selected. The start-ups identified were grouped into innovation clusters and for each of them some examples were inserted. In addition, to develop the model regarding the start-up that focus their offer on the technology of AIoT, I select a total of 24 start-up:

Analysis of the current scenario

For the analysis of the current scenario, it has been exploited the database of Interent of Things projects. The first analysis proposed highlights the predominance of Europe over the other continent in terms of number of projects implemented in its territory (71% of the projects mapped). However, the great influence of projects developed in Italy should be considered. Indeed, it represents 44 % of the total sample. A percentage that is undoubtedly affected by the methodologies used for the research of the projects, that bring to a particular focus on Italian cases. Moreover, it is possible to notice a strong trend of growth from the early 2000s to now. Considering projects' application fields, it is possible to see a dominance by the Smart Factory, that represents the 70% of the cases.

Smart Factory

The term Smart Factory refers to the use of various digital technologies within the factory that, by combining with each other, make the operational processes more efficient and flexible, being able to dynamically coordinate processes, people and machinery. In particular, through IoT technology, a large amount of information related to the operation of the entire plant can be obtained, which, after being processed and analyzed, manage to generate a great value for the management of the factory. Four main specific application related to the Smart Factory domain have been identified:

Production optimization: Production optimization is closely linked to monitoring the progress of production processes, with the goal of optimizing key parameters for each company such as time, cost, quality and safety.
Preventive maintenance: Preventive maintenance consists of a precise maintenance policy that is based on performing maintenance intervention before failure occurrence. To do so, the intervention is scheduled according to predetermined intervals of time or units of use, or prescribed criteria, to reduce the probability of failure. All of this is made possible through the exploitation of IoT and data analytics, which make obsolete an asset management approach based on the "run to failure".
Predictive maintenance: Predictive maintenance can be seen as an evolution of preventive maintenance, discussed in the previous section. The key feature of predictive maintenance is that the interventions scheduling is based on the forecast of trend of one or more parameters linked to the degradation process.
Energy management: This factor is particularly relevant in the manufacturing industry, notoriously the most "energy-intensive" one. There is, therefore, the need to adopt strategies to monitor actual energy efficiency levels. This would make it possible to develop solutions to reduce the various energy wastes present in plants. In addition, energy efficiency is crucial in the context of moving more and more toward sustainable

production, a factor that is gaining considerable importance as a result of increasingly stringent regulations in this area.

Smart Logistics & Supply Chain

With the pandemic we are currently experiencing, there appears to be an increasing need to use cutting-edge technologies that enable to obtain more information about logistics flows (generating a better and more responsive decision-making process). Smart logistics solutions are generally based on optimizing all organizational and strategic operations related to the management, storage and destination of goods. To achieve these goals, it is necessary to make logistics processes (internal or external to the company) as transparent as possible, including analyzing the operations of collaborators, partners and suppliers. In this scenario, IoT enables precise and timely monitoring of all objects connected to the system, enabling companies to organize logistics processes in an optimized way.

Traceability along the Supply Chain: The ever-increasing complexity and variability of supply chains, stimulates companies to invest more and more in asset tracking solutions. Through track and trace solutions, companies are able to significantly reduce inventories through real-time visibility of inventory and shipment levels. As a result, there are significant savings in inventory management costs

Traceability of internal warehouse: Also for this specific application, the principles of visibility are considered as the basic point of any project. Companies are able to achieve great results in terms of work safety, efficiency and a relative reduction in costs, all thanks to the tracking of operators, vehicles and assets within the warehouse.

Logistical assets management: One of the most common applications of logistics asset management is in enterprise fleet management. Companies, in fact, by connecting their fleet via IoT sensors, are able to optimize its performance (in terms of safety, energy consumption, productivity), thanks to continuous real-time monitoring. This possibility is particularly interesting for cold chain management. Some companies, in fact, need to ensure a precise degree of humidity and temperature during the transportation of goods. The ability to continuously monitor these parameters would make management much smoother, optimized and safer.

Smart Lifecycle

In general, the management of the lifecycle of a product (or of an asset), encompasses all those activities of a strategic and operational nature that characterize its production process, which characterize the stages of design, use, market launch, maintenance and finally disposal. IoT would allow companies to develop a holistic view of all phases of the product life cycle. In fact, a connected product would be able to collect data from the creation to the final disposal, which, once analyzed by the company, would be of critical importance in optimizing each of the product's life stages.

Optimization of product development: This application enables companies to make new product development processes more effective. This requires continuous collection of data generated by products (already in the market) connected and equipped with IoT sensors. Some of the main benefits that companies find by using solutions of this type are the reduction of time between product conception and sale (time to market) and the reduction of product development costs. In fact, the goal of companies is to optimize and make more effective the design and development phase of their products by leveraging information from related products already used by customers

Survey analysis

In this chapter, I propose the results of the survey that has been conducted together with the Osservatorio Internet of Things. The survey is composed of 25 questions, and it is inserted in the Annex.

The questions proposed, cover a wide range of topic that better explain the relationship of each company with the technologies analyzed. The aspects on which the questions focus on are:
-The effect of the current economic and political instability over the performances of the company.
-How the companies are trying to obtain the funding of the PNRR, and how it has impacted on the investments budgeted by the company.
-The relationship of the company with the IoT technology (if there is a strong awareness inside the company, if the theme is relevant for it and if it

has already implemented IoT projects in the past).
-If the company is investing in services as well, together with the IoT solutions. The survey further deepens on who is the provider of this services and on what are the point of weaknesses on outsourcing those services.
-The main driver for the implementation of IoT project.
-The most influential professional figure inside the company for the implementation of IoT projects.
-If and how the company has exploited the data generated by IoT projects (and, eventually, why they have not been exploited).
-The feedback about the project already implemented.
-The main barriers (if any) that prevent from the launch of IoT projects.
-The most crucial phase of an IoT project.
-Future plan regarding the implementation of IoT projects and, eventually, which kind of application of Industrial IoT the company would like to exploit
-The objectives that the company would like to achieve with new IoT projects
-The development of the company in terms of cybersecurity in IT systems.
-The willingness of the company to collaborate with third parties for integrated IoT projects (and, eventually, with which actors).
-The impact that IoT projects implemented had on some specific performances

Directions of future development

To conclude the thesis work I decided to propose an analysis of the future developments of the technology of IIoT by analyzing the main trend that are developing nowadays around this technology. To do that, a research on the website "Crunchbase" has been conducted, with the aim of finding which are the offering of IoT start-ups that developed over the last years.
The start-up found during the research were subsequently clustered in the following groups:

AIoT: is the joint use of Artificial Intelligence and IoT, with the aim of creating synergies between IoT tools and AI algorithms. Indeed, the great advantage of using artificial intelligence in data analysis is the ability to generate predictive analytics, which would allow to anticipate problems or possible opportunities for improvement within the factory processes. And thanks to IoT devices, the algorithm will have accurate and reliable data to analyze, which is an essential factor for the effectiveness of AI.
Two sub-groups where then identified, based on the objective for which these solutions are sold to companies. The first one is characterized by the use of the above technologies based on the improvement of the performance of the production process (such as quality, speed, productivity, efficiency). The second, focuses on improving the environmental sustainability of companies that adopt such solutions (through, for example, the reduction of greenhouse gases).

Cybersecurity: with the usage of IoT devices, an additional great level of complexity in terms of cybersecurity is added to companies, due to the integration of the physical world with the digital one. In fact, the countless devices that are used to exploit the power of IoT (creating a connected and intelligent factory) make companies even more vulnerable to possible threats and violations. For these reasons, the theme is of fundamental importance for enabling a massive spread of IIoT solutions within the factories.
Within the cluster of Cybersecurity start-up, a sub-group of companies focusing on Blockchain technology has been inserted. One of the most important features of this technology, that can result to be critical for the cybersecurity of the companies, is the decentralization. In the blockchain, data is shared across multiple "nodes" that use precise software to ensure that data remains unchanged. As a result, since all information are decentralized, it is more difficult for an attack to be able to tamper with the information.

Metaverse & Digital Twin: The term Metaverse refers to a digital universe that users can access, through the technologies of Augmented Reality (AR) and Virtual Reality (VR) and live virtual experiences. This highly innovative technology can also be used on an industrial level, even if the applications in this field, as mentioned before, are still very limited. In this case we talk about Industrial Metaverse, that uses the technologies of AR, VR and Internet of Things to improve the efficiency and productivity of industrial

companies.
If we consider the application at the industrial level, one of the key technologies on which the Metaverse is based is that of the Digital Twin, already developed in some companies. Thanks to digital twins, in fact, it is possible to duplicate any environment and process, allowing to perform experimental and predictive analysis.

Finally, a model was developed with the aim of analyzing more in depth the trend of AIoT, which the most spread among the ones mentioned before. The focus was put on two specific characteristics of the offering of the start-up analyzed, which are:

Scope of the solution: the two main macro-areas of application that emerged are the improvement of the factory's production performance and the increase of the company's environmental sustainability. In the first case, the combination of IoT and AI is exploited to optimize the production process. The predictive logic of AI enables services such as predictive maintenance and improvements in various performances such as quality control, optimization of production scheduling, maximization of machinery utilization, increase in productivity, and increase in occupational safety

Specificity of the solution: the objective is to understand whether the offerings are extremely focused or, on the contrary, can be applied to a broad spectrum of cases. To define that I took into considerations both the number and variety of sectors in which the solution can be used and the number and variety of applications included in each proposal.

Conclusions

Thanks to both the analysis of the database of IIoT projects implemented and the survey conducted, it was possible to understand which is the state-of-the-art of this technology.
With the first analysis mentioned, a trend of growth in terms of number of projects implemented year after year has been highlighted. Moreover, looking at the distribution of the projects considering the application area, it emerged that the Smart Factory is the most spread one, followed by Smart Logistics and finally, by Smart Lifecycle application area.
From the analysis of the results coming from the survey it was possible to highlight some important points. First of all, the awareness of IIoT solutions among Italian companies is growing and the vast majority of the company surveyed has already implemented a project. In this sense, the PNRR has been important considering that 45% of the companies increased their investments in IIoT solution after the implementation of the plan. Considering which are the reason for which companies focus on IIoT, the most selected one was the possibility to reach benefits of efficiency (such as reduction of production costs and time). On the other hand, regarding the barriers met, there are both internal motivations (like the lack of internal competences and expertise) and external ones (like economic instability or lack of raw materials). Regarding the trend towards the servitization, the majority of the company declared to have activated additional services for their projects, with a predominance of information services. Moreover, from the surveys it was possible to highlight the difficulties that companies still have in the exploitation of the value of the data. Half of the respondents is currently not exploiting the potential coming from data analysis (and many of them has not even planned to do that in the near future).
With the research of innovative start-up carried out, it was possible to identify the main trends of development of the IoT technology. It emerged that the two most spread ones are the AIoT and the Cybersecurity. Moreover, a very innovative technology that is developing in the last years is the Metaverse even though, we are still far from a massive adoption of this solutions inside the factory.
Finally, with the model proposed to deepen the trend of AIoT, it was possible to highlight that the applications that focus on the improvement of production performance are still more spread than those that focus on the environmental sustainability of companies. Moreover, it emerges how the latter ones tend to have a high level of specificity being applicable only to specific context. On the other hand, the start-ups that developed products and service for production performances improvement are usually applicable to a great variety of manufacturing contexts.