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THE IMPACT OF 4th INDUSTRIAL REVOLUTION (4IR) ON NON-DESTRUCTIVE TESTING METHODS

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***Abstract*—The 4th Industrial Revolution (4IR) is developing, leading the transition to the post-industrial era. Both the industry and the business world as well as the civil society, have already realized that the world as it exists is about to change due to the 4th Industrial Revolution. Many countries and stakeholders, realizing (4IR)'s importance, have already incorporated it into official policies while the companies at the forefront are called upon to integrate a variety of new technologies. Among other technologies, in this context, the evolution of non-destructive testing is of significant importance, having a positive impact not only on productivity but also on numerous technical, managerial, and economical aspects of the final product. The present work attempts to highlight this issue and form the basis for relevant future research.**

***Keywords*— Industry, Automation, Technological Progress, Non-Destructive Testing, 4IR, 4th Industrial Revolution, Inspection Techniques.**

I. INTRODUCTION

A rapid development of technology has been observed the last two centuries. Especially the end of the 20th century is characterized by the development of cutting-edge technologies. The 4th Industrial Revolution (4IR), also known as "Industrial Internet of Things", will empower a technological transformation, through which new construction possibilities will be utilized while people's living and working conditions, interactions with each other and the global economy will change. As a result, significant competitive advantages are expected to develop for any organization operating and growing in the global market.

The representation of 4IR in production and manufacturing is Industry 4.0 (I4.0). A cutting-edge field where I4.0 as a part of 4IR leaves its mark is non-destructive testing. The role of non-destructive testing in industry, economy, environment, and construction is crucial and requires the attention and interest of the scientific community. The present work presents the necessary aspects for the study of non-destructive testing in the context of the 4th Industrial Revolution, attempting to highlight their evolution in it.

II. THE 4TH INDUSTRIAL REVOLUTION (4IR): HISTORY AND CHARACTERISTICS

Arnold Toynbee was the first to use the term Industrial Revolution in his lectures [1]. The journey of the industrial revolutions begins at the end of the 18th century, where the 1st Industrial Revolution (1760-1840), which was based on mechanization, water and steam power, benefited mass production leading to the creation of the factory [2], which was determined by the mechanization of the textile industry. Furthermore, the locomotive changed transportation in its entirety. The 2nd Industrial Revolution led from the United States, is chronologically placed between 1870 and 1969 and is characterized from mass production, assembly line and electricity [3]. Economies of scale have emerged as a result of specialization and machine modernization. The following situation, the 3rd Industrial Revolution (1970-2020), is characterized by the invention of computers and automation. Governments and academic institutions all over the world massively invest in research and development projects resulting in the development of technical advances [4]. The 4th Industrial Revolution is based on the 3rd in terms of information technology, as it uses computers to evolve automated systems, but is a major step towards the future.

The term "4th Industrial Revolution" was launched in 2011 in Germany by Henning Kagermann, the head of the German National Academy of Science and Engineering, as an attempt to describe the digital transformation of manufacturing. 4IR could be characterized evolutive rather than disruptive but in a revolutionary context. According to Klaus Schwab, the three reasons that demonstrate the transition to a new industrial revolution and not just the extension of the previous one are velocity, scope, and systems impact. 4IR describes "[…] the use in industrial production of recent, and often interconnected, digital technologies that enable new and more efficient processes, and which in some cases yield new goods and services." [5]. The key innovations of 4IR - Internet of things (IoT), artificial intelligence (AI), augmented reality (AR), cloud computing cyber, data exchange, big data – have not only strengthened the manufacturing technologies but also changed the philosophy around them.

Fig. 1. Pillars of the Fourth Industrial Revolution

The 4th industrial revolution has numerus advances on many fields and operates through the following disruptive technologies [6]:

- Mobile devices
- Internet of things platforms
- Location detection technologies (electronic identification)
- Advanced human-machine interfaces
- Authentication and fraud detection
- Smart sensors
- Big analytics and advanced processes
- Multilevel customer interaction and customer profiling
- Augmented reality/ wearables
- On-demand availability of computer system resources
- Data visualization and triggered "live" training.

Technical, economical, and demographical sectors are those susceptible to maximum effect due to 4IR [2]. Figure 2 presents the Impact of 4IR on a range of industries.

Fig. 2. Impact of 4IR on a range of industries

Classifying the above technologies into four key categories – cyber physical systems, Internet of Things, on-demand availability of computer system resources and cognitive computing – allowed the term “Smart Factory” to emerge. This term refers to a production environment which combines virtual and physical systems of manufacturing and operates without human intervention.

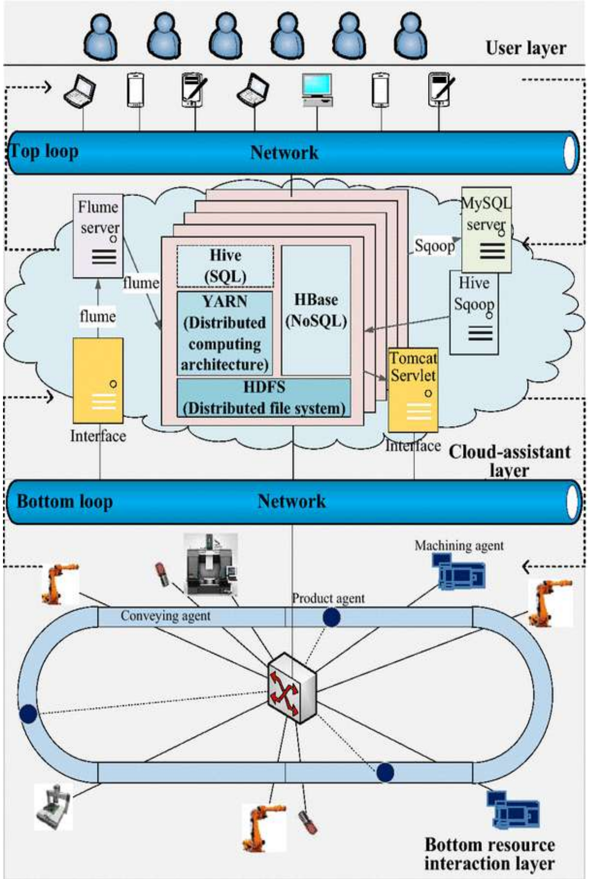

Fig. 3. The structure of the Smart Factory

III. NON-DESTRUCTIVE TESTING

Non Destructive Testing (NDT), or Non Destructive Inspection (NDI), or Non Destructive Evaluation (NDE), are the tests used to identify certain properties or characteristics of a material and to detect defects and imperfections without destroying the specimen subjected to them. It serves the purpose of keeping the sample usable and fully functional in terms of material composition while retaining all its properties intact. According to The American Society for Non Destructive Testing “Non-destructive testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system” [7].

Nowadays, industry is increasingly using non-destructive testing to ensure that the material subjected to testing is not damaged in any way. The benefits of these techniques are numerous with the main ones being non-alteration of the properties of the material, flexibility, repeatability, saving of time and consequently money. Additionally, the inspection can be carried out according to international standards and this is an important part of product certification.

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Non-destructive testing is now an essential tool in a wide range of applications. The applications of non-destructive testing can be found in oil, gas and petrochemical industries, construction, medicine, aerospace, shipping etc. The uniqueness and usefulness of non-destructive testing has attracted the attention of experts from manufacturing and research.

The most popular among the available methods are Magnetic Particle Testing (MT), Liquid Penetrant Testing (PT), Radiographic Testing (RT), Ultrasonic Testing (UT), Electromagnetic Testing (ET) and Visual Testing (VT). Other methods such as Acoustic Emission Testing (AE), Laser Testing Methods (LM), Leak Testing (LT), Magnetic Flux Leakage (MFL), Neutron Radiographic Testing (NR), Thermal/Infrared Testing (IR) and Vibration Analysis (VA) are also used [7]. Wang et al [8] categorize NDT techniques into five groups (Figure 4): "(1) VI (i.e. those visible to the human eye); (2) acoustic wave–based techniques, such as AE, nonlinear acoustics and ultrasonic waves; (3) optical techniques, which include IRT, THz testing, shearography, DIC; (4) imaging-based techniques, for example, X-ray/neutron radiography/tomography and micro-tomography;4 (5) electromagnetic field–based techniques, such as eddy-current testing, remote field testing, magnetic particle inspection and magnetic flux leakage testing".

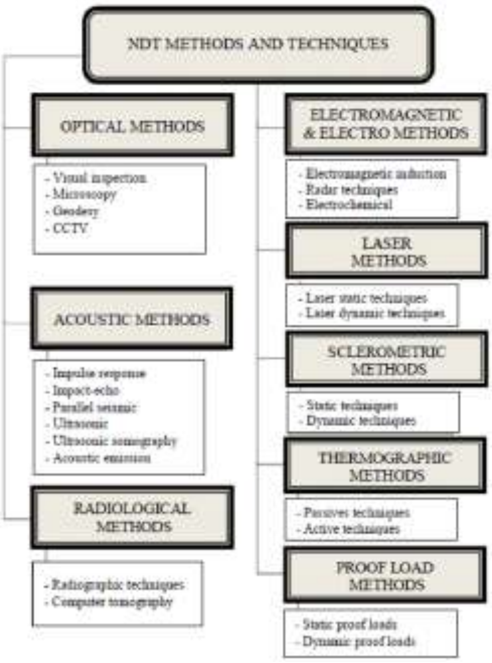

Fig. 4. Non destructive methods for diagnostic testing of building structures

Some of the aforementioned methods are more advanced than others. The variety of techniques allows the choice of the most proper method taking into consideration the advantages and disadvantages of each one as well as the availability of its application and the prevailing conditions. As material changes along the product life cycle different NDT methods may be suitable at each stage of it.

NDT is not just a highly valuable technique. It is an emerging industry that is constantly shaking ground depending not only on technology but on specialized certified personnel as well. ISO 9712:2012 as it was revised by 9712:2021 specifies requirements for principles for the qualification and certification of personnel who perform industrial non-destructive testing (NDT) [9].

However, apart from its undoubted advantages, there are some points that are under consideration such as cost effectiveness and inspection reliability [10].

IV. THE IMPACT OF IR4 ON NDT

The evolution of non-destructive testing in the context of the 4th Industrial Revolution is extremely interesting as it is characterized by major challenges. One way to understand the relationship between non-destructive testing technology and the 4th Industrial Revolution is to examine the former under the umbrella of the latter. The 4th Industrial Revolution, through I4, has converted NDT 4.0. NDT has already applied all four I4 basic principles: 1) interoperability, 2) technical assistance, 3) information transparency and, 4) decentralized decisions.

Another way is to look at their parallel paths and overlapping areas. The relationship between the industrial revolutions and the evolution of non-destructive testing is successfully described in the study by Liu et al [11] as a parallel course from manually applied NDT during Industry 1.0, to the use of instruments (Industry 2.0), to a digital, automated NDT (Industry 3.0) up until the current version of NDT which is not only digital and automated but also visualized. During this evolution the dependent degree of operator appears to be declining giving its place to the degree of intelligence.

The evolution of NDT is guided by improvement in four pillars - quality, productivity, safety, and sustainability. This can be translated into improvement in accuracy, efficiency and data collection, reduction of errors and reworks as well as new perspective on accessibility [12].

The positive contribution of the basic structural elements of 4IR at non-destructive tests is indisputable. Big data, wireless sensors, Artificial Intelligence, and the IoT have already established their position in the field. Consequently, the impact of (I4)'s applications, and more specifically Artificial Intelligence, leads to reduced inspection time intervals, reduction of inspections resulting in productivity and addresses issues related to the need for qualified personnel. Furthermore, Internet of Things, cloud computing and big data bring together all the advantages of information exchange, combination of knowledge, statistical analysis.

A. **Artificial Intelligence and big data in NDT –**

Up until recently, all the basic processes of NDT such as planning, customization and data interpretation, were made excursively by humans. This resulted in errors, time delays and required specialized staff. Nowadays, artificial intelligence, by

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simulating and expanding users' intellectual characteristics, has offered a significant input in the field with automated solutions for non-destructive testing. The humanization of machines, as it is called, is a procedure during which machines learn from humans (machine to human) and from other machines (machine to machine) as well. Internet of Things gives access to the machines, through search engines, to a huge amount of information. Artificial Intelligence can form thought to machines, but to do so, behavioral models that arise from the analysis of big data are necessary. The copy of human thought is achieved through Artificial Neural Networks [13]. While data is initially raw information, their digitization produces a large volume of unstructured data which ends up being the input of the above process.

In NDT, Artificial Intelligence is approached through two primary areas [14]: Artificial intelligence techniques for the automatic interpretation of data from non-destructive testing - Knowledge-Based Systems (KBS) [15], as well as the development of Artificial Neural Networks (ANN) and signal processing techniques [16] used so any defects in NDT can be detected in a more efficient way.

Artificial intelligence is, also, the main technology behind computer-controlled robots. The absence of human factor in situ is an innovation that robots brought in the NDT sector. This technique that is constantly evolving, involves robots properly programmed which are able to reach inaccessible places and to execute detailed inspections in unsafe and hazardous environments. Autonomy, efficiency, almost unlimited mobility, and integrated process are not the only advantages that robots have to offer. Non-destructive tests performed by robots enhances the safety of procedures due to the remote monitoring. A great example of the use of robots in NDT is both the crawling and climbing robots which have been developed to be used at a range of difficult to access situations such as highway bridges, tunnels, wind turbine blades and towers, hull ships, pipelines, nuclear installations, etc. [17]. Robots are not only able to execute visual inspections but also ultrasonic, acoustic, thermal and others as well.

Unmanned aerial vehicles (UAV) and Autonomous Underwater Vehicles (AUV) can also be used in NDT. Such an example is the mooring chain inspection systems such as the “PANDORA” AUV (Figure 5) [18].

Fig. 5. PANDORA AUV

B. **The use of cloud computing and real time data in NDT** –
One of the most challenging areas in the field is obstructed data sharing [19]. Data collected in the field are not easily transferred which results in lack of sufficient information. Data processing and storage is also a significant issue. Furthermore, the indirect communication between the stakeholders prevents the immediate solution of problems and the real time constructive contribution of the team.

Cloud computing enables virtualization of servers and provision of computing resources via the Internet [13]. The above are now feasible in non-destructive testing controls. The immediate transfer of data through cloud computing and wireless communication, the rapid analysis and the modification of the process based on the results, contribute to an improved outcome.

C. **User-friendly and wireless applications and equipment** –

An issue of great importance in non-destructive testing is the difficulty of using the equipment as well as analyzing the results produced in situ. This becomes even more intense when there is no qualified and well-trained staff. New type cameras and advanced screens for visualization supporting, radar applications and user-friendly devices are now available, creating improved control conditions and giving to less trained staff the opportunity to participate. Figure 6 shows one such example on tomographic structural investigations. A step forward to this direction, is on-site data-processing which offers autonomy and speeds up the error correction process.

Fig. 6. Wireless equipment and intuitive user interfaces

D. **Conducting NDT through Augmented Reality –**
Augmented Reality is a valuable tool in NDT that promotes smart inspection systems. Graphically illustrated dataset can now be displayed in the physical world, e.g. on the object under inspection. Such systems apply a testing process that consists of data recording, processing and visualization [19], enabling users to project test results directly onto the measured component. 3D augmented visualization is also used for training operators making the NDT process more understandable for non-experienced users [20].

E. **IoT and NDT –**
NDT has greatly benefited from the fundamental components - sensors, connectivity, data processing, user interface - of I4 and more specifically of Industrial Internet of Things (IIoT). Smart inspection devices, advanced data collection and analyzing

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applications, internet networks connectivity for information exchange and monitoring, composes IoT. Some of the basic aspects of IoT that contribute to the advancement of NDT are the 3D volume data, live date file management, big data, remote monitoring, communication devices etc [21].

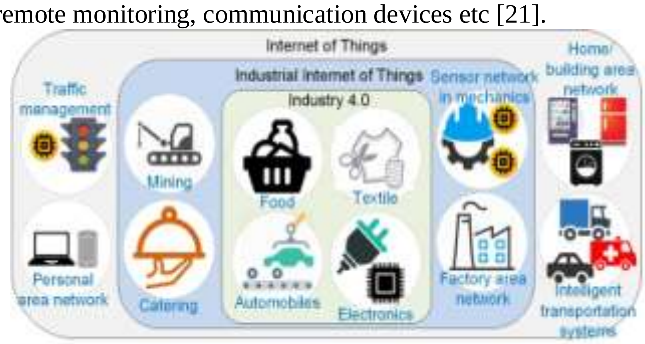

Fig. 7. Internet of Things (IoT), Industrial Internet of Things (IIoT) and Industry 4.0

V. CONCLUSION

The technology of non-destructive testing has entered a new era due to the applications offered by the 4th Industrial Revolution. Artificial intelligence, Augmented Reality, wireless, high-volume data, neural networks, cloud computing are some of the major contributions of the 4IR in the field.

NDT is becoming state-of-the-art technology, bringing with it a wealth of benefits. First of all, user-friendly surfaces and new types of devices offer easier handling and ease of learning. The handling of the equipment is also facilitated by wireless technology which, in combination with internet and cloud computing, allows the exchange of data in real time as well as the feedback from a support mechanism that could be located anywhere. The rapid big data analysis enhances the on-site improvement of the test. Robots and unmanned vehicle systems eliminate hazards and implement the most difficult control cases. Finally, Augmented Reality creates new conditions for displaying and understanding audit findings, paving the way for more comprehensible and effective audits.

NDT in the context of 4IR is becoming faster, more accurate, more interactive, more automated, more independent, more precise, more intelligent while at the same time contact-less, mind-less, wireless.

However, one should not overlook the dangers and threats that the technological revolution may bring, with emphasis on the consequences on humans. The technological advances of the 4th Industrial Revolution undoubtedly improve productivity and the economy but should not be at the expense of human resources by sacrificing labor rights or the environment.

One of the most important threats that must be taken seriously by the stakeholders is the reduction of the need for specialized staff as well as the fact that the same process may now require fewer people. In addition, the danger of security is always present in the interconnection era. The more data is exchanged and stored over the internet, and the more functions are performed wirelessly, the more the system is at risk. The likelihood of cyber attacks, hαcking, data interception, system malfunctions to happen is always present and for this reason the system must be properly fortified.

Covid-19, has also left its mark which will become apparent in the future when technology will focus on minimizing human contact and intervention as well as remote control and valuable insights at anytime from anywhere around the world. The mutation brought about by the pandemic in the daily functions of life and work greatly enhanced the use of digital tools. One could say that the pandemic acted as an accelerator of the 4th Industrial Revolution.

The future of NDT during IR4 is very promising. Research in the field is ongoing and more and more applications become available. In addition, we should not overlook the fact that we are on the threshold of the 5th Industrial Revolution which, according to experts, will be characterized by mass customization and cyber physical data.

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