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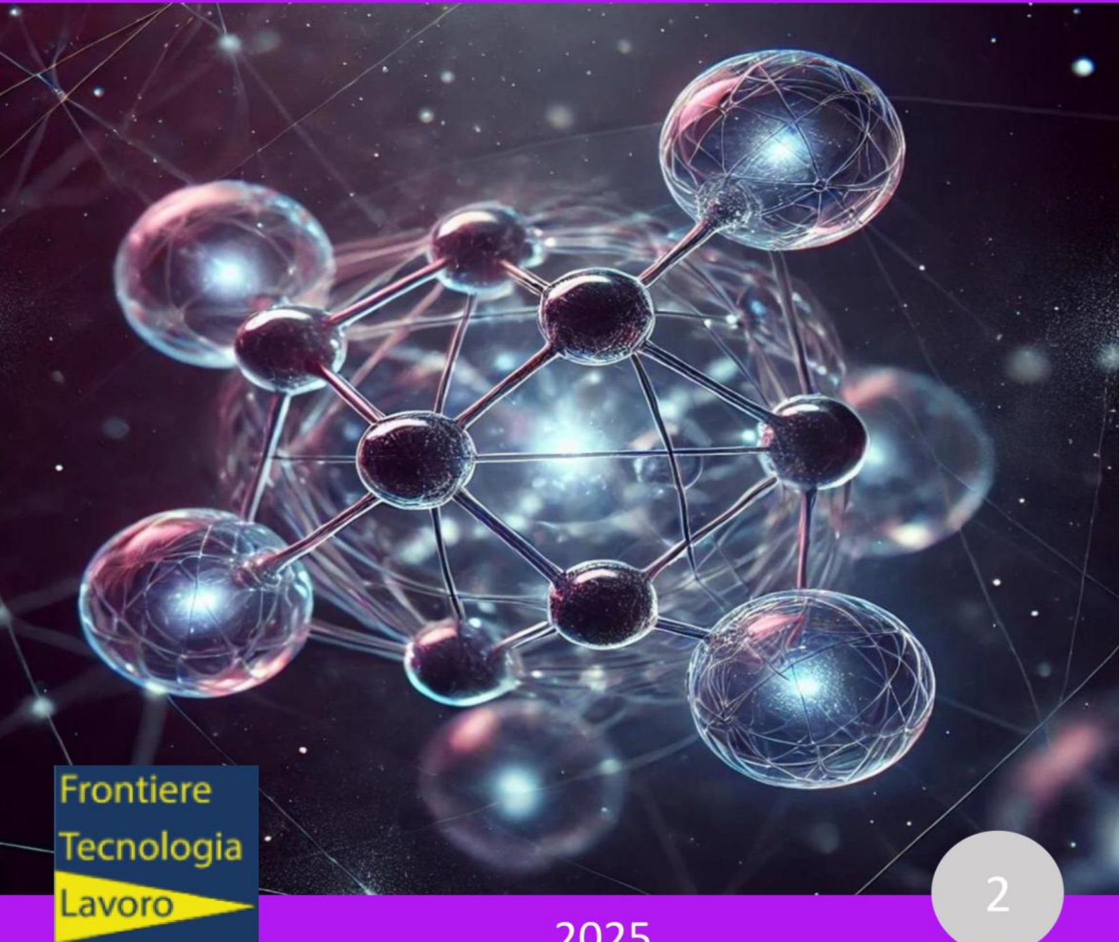

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What is it? This is a scientific dissemination website that studies the impact of new technologies on the world of work. Changes today are very fast and exponential. Professions are not static but very dynamic, so the ongoing evolutions can make them obsolete, transform them, or create entirely new ones. What skills will be necessary to face all this? Upskilling and reskilling, but not only.

Why? After 25 years of research, I have realized that to go beyond the boundaries, numbers are not enough. Traditional approaches are obsolete and tied to the old way of doing research. Today, we need to study the weak signals that are right before our eyes but that we see without really noticing. Stopping to consider these signals and imagining multiple possible futures will be the task of Frontiere. Traditional sources respond in real-time but only photograph the present. Today, however, there is a need to make predictions at least five years ahead, without neglecting the past and without forgetting that every topic addressed has a history to consider.

Who is it for? It's easy to make long-term predictions that cannot be verified. I am convinced that the research world needs an immediate confrontation with the world of education and orientation, and with young people who risk studying for professions that may not exist in a few years. They will be here to exchange opinions with the undecided, the disoriented, and those who intend to start over. Young people need to understand that there is a world above and a world below in the job market. A world of those who program algorithms (few and well-paid) and those who work for algorithms (many and poorly paid). We need to understand what to do to escape a job market that risks condemning young people to €1,000 per month salaries for life.

How will it be? Each topic will be addressed with light publications, with a strong emphasis on temporal depth. The publications will be accompanied by short videos (elivri) that get straight to the point. There will be an open chat for young people on the future scenarios of work, the profiles required, and the necessary skills.

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INTRODUCTION

THE MEANING OF TECHNOLOGICAL REVOLUTIONS

Technological revolutions have always profoundly redesigned the social, economic, and professional structures of human societies. From the advent of the steam engine to the threshold of quantum computing, each technological transformation has generated not only new tools but also new professions, skills, and cultural paradigms. This contribution analyzes the evolutionary path of these revolutions, focusing particularly on the recent development of quantum computers and their potential future implications for contemporary society.

The historical significance of technological revolutions. Technological revolutions represent moments of discontinuity in human history, characterized by the introduction of innovations that radically change production processes, social relations, and professional skills. Each technological revolution has brought with it a profound change that has redesigned not only production methods but also the very structure of professions and the skills required by the labor market. The analysis of these phenomena allows us to understand how societies have historically responded to transformations induced by innovation, providing useful interpretative keys to face current and future challenges. Change is inevitable, and with it always come new opportunities for growth.

From the industrial revolution to the digital age. The industrial revolution, characterized by the noise of machines and steam locomotives, radically transformed the society of the time. Among textile mills and foundries, new professional figures such as engineers, factory directors, and specialized mechanics emerged, becoming essential to drive innovation and technological progress. It was not just about the introduction of machines but the creation of a new professional ecosystem composed of individuals capable of understanding, designing, and managing complex technological systems. Making a temporal leap of about a century, we arrive at the digital age, where computers went from the size of a room to pocket wonders. The global connectivity offered by the Internet has fostered the emergence of a new generation of professionals: electronic engineers, programmers, cybersecurity experts, cloud computing specialists, and data scientists, who have become indispensable for navigating the informational ocean of the digital age [1].

CHAPTER 1

THE ADVENT OF QUANTUM COMPUTING

Current state of quantum technology. Despite their enormous potential, quantum computers are still in an early stage of development but already represent a concrete reality in the contemporary technological landscape. These systems have existed and been usable for some time, although they are still in the experimental phase. They are not yet widespread among the general public or in companies, but technology giants like IBM and Google, along with other specialized entities, have developed and actively use them to explore their potential and improve their performance. The theory of quantum computing began to take shape in the 1980s, thanks to the insight of Nobel laureate Richard Feynman [2] and other scholars who understood the intrinsic limits of traditional computers. However, the transition from theory to practice took nearly 35 years: it was only in 2016 that the first functional quantum computers appeared, marking a decisive turning point in the development of this revolutionary technology.

Evolution of computational capabilities. From 2016 to today, the development of quantum processors has seen significant progress, especially in terms of the number of "qubits" (fundamental units of quantum information) [3]. The more qubits a processor has, the greater the amount of information it can process. From the initial five qubits of the first models, we have now reached processors with more than a thousand qubits per single chip, highlighting the rapid acceleration of this technology. A crucial aspect remains the quality of the qubits themselves. Current systems do not yet produce completely error-free results, although a study published in Nature has shown that existing quantum computers, with more than 100 qubits, when used together with "error mitigation" algorithms (error management tools), can provide results comparable to those obtained by traditional supercomputers with brute force algorithms [4].

Quantum supremacy: from theory to reality. Quantum supremacy represents a fundamental milestone in the development of quantum computing, defined as the moment when a quantum computer is able to solve problems that a traditional supercomputer could not complete in humanly acceptable times. This turning point was reached in 2019 when Google presented Sycamore, a quantum computer capable of solving in 200 seconds a problem that would have taken the most powerful traditional supercomputer about 10,000 years [5]. As highlighted by theoretical physicist Michio Kaku, this achievement has "announced a disruption that can change the entire computing landscape and turn every aspect of our daily lives upside down." The following year, the Quantum Innovation

Institute of the Chinese Academy of Sciences declared that its version of the quantum computer is 100 trillion times more powerful than a conventional supercomputer, further emphasizing the revolutionary scope of this technology [6]. The real turning point will be reached when these systems achieve what is called "practical quantum advantage," i.e., the ability to solve precisely the real-world problems that are unsolvable even by the most advanced supercomputers [7].

CHAPTER 2

FUNDAMENTALS OF QUANTUM COMPUTING

Qubits and fundamental quantum principles. At the heart of quantum computing are qubits (quantum bits), typically realized through subatomic particles such as photons or electrons. Unlike classical bits, qubits exploit three fundamental properties of quantum mechanics: first, "Superposition," which occurs when a qubit can exist simultaneously in multiple states, allowing an exponentially richer representation of information compared to classical bits. Only at the moment of measurement does the system "collapse" into a defined state; then "Interference," which occurs when, during computation, the states of the qubits are manipulated so that they combine. "Constructive" interference amplifies the correct solutions, while "destructive" interference eliminates the wrong ones, guiding the algorithm towards the right answer; finally, "Entanglement," which describes a deep correlation between two or more qubits. A measurement or modification on an entangled qubit instantaneously influences the others, regardless of distance. Einstein called this phenomenon "spooky action at a distance," but today it represents a fundamental computational resource.

Quantum logic: examples and implications. Quantum logic transcends the "true/false" dualism of classical logic, introducing a range of intermediate possibilities. A popular example is that of "superposition" in a situation of sentimental uncertainty: until a response is obtained, all possibilities coexist simultaneously. This logic allows quantum computers to tackle problems that would require millennia of classical computation, with potentially much lower energy consumption. However, it is important to emphasize that a deep understanding of quantum phenomena remains a conceptual challenge: we are able to manipulate and calculate them mathematically, but their ultimate meaning continues to spark philosophical debates among physicists.

The development of quantum algorithms. The development of effective quantum algorithms is still in its early stages and requires a radically different conceptual approach compared to classical programming. Fundamentally, a paradigm shift is needed in the way of thinking and training new generations of scientists and engineers, who will have to master a logic that is no longer binary but quantum [8].

Quantum computers: telescopes for science, not universal supercomputers. It is essential to avoid misunderstandings about the future impact of quantum computers. They are not intended to replace classical computers (laptops, smartphones, servers) in everyday activities. A more fitting analogy is that of the telescope: it does not replace the naked eye or the microscope but is a specialized tool for exploring specific domains. Quantum computers are primarily seen as powerful tools for investigating quantum physics itself and simulating complex physical systems (particle physics, condensed matter). They could be more accurately defined as "generators of arbitrary correlations between many parts" rather than "computers" in the traditional sense. A future of hybrid architectures is envisioned, where classical and quantum computers will collaborate, each leveraging their strengths in different domains [9].

The value of the development path. The road to fully operational quantum computers is long. Google's "Willow" chip, for example, has about 105 qubits, but millions will be needed for truly powerful machines. However, as with space research, the journey itself will generate significant value. It is emphasized that the need to manipulate matter at unprecedented levels to control qubits will lead to fundamental discoveries in physics and materials science, regardless of the final outcome of quantum computer research [10].

Speculations about the future beyond the boundaries of current science. Some bolder visions, such as those discussed by physicist Michio Kaku, hypothesize that quantum computers might even detect phenomena related to alternative realities or parallel universes, generating patterns or anomalies interpretable as information coming from other dimensions. Although fascinating, these ideas remain highly speculative and require rigorous scientific investigation. The realization of powerful quantum computers represents a scientific and technological marathon whose value lies as much in the discovery journey as in the final goal. Quantum computing represents more than just a speed increment; it is a fundamental change in the paradigm of information processing. Preparing for this revolution requires investments in research, the development of new skills, and a cultural adaptation to embrace the complexity and opportunities offered by the quantum world. The greatest challenge may be educational and cultural: training a new generation of scientists, engineers, and decision-makers capable of thinking "quantistically," overcoming the limits of classical binary logic that has dominated our approach to the world for centuries. In this transition lies perhaps the deepest impact of the quantum revolution: not just new technologies, but new ways of conceiving reality and addressing the complex problems that await us in the future [11].

CHAPTER 3

TECHNOLOGICAL CHALLENGES AND DEVELOPMENT PROSPECTS

Quantum computing represents one of the most discussed technological frontiers of our century, characterized by a heated debate between enthusiasts and skeptics. Here, we critically analyze the real capabilities of the technology, its structural limits, and the divergent prospects in scientific continuity, integrating often overlooked visions in mainstream discourse.

Intrinsic technological limits: beyond the hype. The development of quantum computing faces unique technological challenges. The main obstacle lies in the fragility of qubits, subject to "decoherence," i.e., the loss of quantum properties due to interaction with the environment. While classical computers operate at room temperature, quantum systems require extreme cryogenic conditions, close to absolute zero (-273°C), and advanced electromagnetic shielding to be captured and manipulated. Decoherence drastically limits the useful time for calculations: even IBM's superconductor qubits maintain coherence for only 100-200 microseconds, insufficient for complex algorithms. This need for extreme operating conditions represents one of the most significant obstacles to the large-scale diffusion of this technology [12]. Overcoming decoherence is crucial for building stable and large-scale quantum computers. Despite these challenges, the interest is enormous.

Specialized startups, tech giants like Google and IBM, and governments worldwide are investing huge resources, aware of the revolutionary potential. However, there is a risk of a "quantum winter," a period of disillusionment and investment decline, should practical progress be delayed.

Quantum computing: hardware challenges and reality beyond the myth. From a hardware perspective, two crucial aspects are identified: the first concerns "error management," as many of the most interesting algorithms require the use of logical qubits capable of producing reliable results. Quantum error correction represents a crucial frontier of research. Without effective error correction, as the size and complexity of a system increase, quantum calculations become unreliable. Developing effective error correction protocols is fundamental for the scalability of quantum systems, but this process requires a delicate balance between error correction and the maintenance of essential quantum properties [13]. The second refers to "scalability," as some particularly relevant algorithms would require millions of qubits, while we are currently in the order of thousands. Increasing the number of qubits exponentially worsens the so-called "quantum noise." To achieve "fault-tolerance" [14], millions of physical qubits would be needed to create a single reliable logical qubit. Scalability thus clashes with unresolved engineering problems: IBM's current 1,000-qubit architecture requires 10 km of superconducting cables and room-sized cooling systems. To double the number of qubits, thermal insulation must be improved by a factor of 8, an unsustainable progression with current technologies [15]. Contrary to common narrative, quantum advantages are "problem-specific," meaning the real advantages offered by quantum computers are not general or universal for all types of problems but only manifest in specific problems for which quantum algorithms are designed to be more efficient than the best classical algorithms. In other words, a quantum computer demonstrates a quantum advantage only when it surpasses the performance of the best classical computers in solving a particular problem, not in a generalized way for any computational problem. Shor's algorithm [16] for factorization shows exponential accelerations, but for 93% of industrial problems (linear optimization, machine learning), the advantage reduces to a quadratic factor, meaning the calculation speed does not grow exponentially but at most with the square of the problem size. In sectors like logistics, a 10,000-qubit quantum computer would offer only marginal improvements over evolved classical algorithms. In short, we are facing the illusion of absolute speed.

Application prospects. Despite the challenges, interest in this technology is rapidly growing. Startups like IonQ and Psi Quantum each raised over 600 million dollars in 2021 to develop their quantum computer projects, while in Europe, Pasqal, founded among others by Nobel laureate in physics Alain Aspect, is already able to offer industrial solutions. The potential applications of quantum computing are manifold and range from logistics optimization to financial management. Concrete examples can be cited: "managing the logistics of a fleet of vans" or "optimizing an investment portfolio of a bank," calculations that must be completed within well-defined time windows to be effectively useful [17]. However, quantum computing certainly lives a paradox: since hardware progress from 5 to 1,000 qubits will be tangible in about a decade, practical applications remain elusive outside specialized niches. The challenge is not so much engineering as epistemological, requiring a rethinking of the dominant theoretical models. The inclusion of critical voices [18], for example, does not weaken but strengthens the field, forcing a confrontation with physical and mathematical limits too often removed. The plausible future will not see omnipotent quantum computers but hybrid ecosystems, where classical and quantum technologies will coexist, each optimized for specific domains. The historical lesson is very clear: every technological revolution creates myths and disillusionments. The task of the scientific community is to preserve methodological pluralism, avoiding both uncritical triumphalism and sterile pessimism. Only through this dynamic balance can we distill the real transformative potential of quantum computing.

Towards a new technological paradigm. The evolution of technological revolutions, from the steam engine to quantum computers, thus demonstrates how humanity has constantly redefined its limits through innovation. If previous revolutions have radically transformed social and professional structures, quantum computing promises to go further, altering the very foundations of our ability to process information and solve complex problems. As highlighted by the path traced, each technological revolution has generated not only new tools but also new professions and skills. The quantum revolution is no exception, requiring professional figures capable of operating at the intersection of physics, computer science, and advanced mathematics. The rapid progression observed in recent years, from achieving quantum supremacy to increasing investments in the sector, suggests that we are only at the beginning of a transformation destined to profoundly redefine the technological landscape of the 21st century, with implications that will likely extend to all areas of contemporary society [19].

CHAPTER 4

THE END OF SILICON: DAWN OF A NEW COMPUTATIONAL ERA

Fundamentals, challenges, and future prospects. Quantum computing today represents one of the most promising and revolutionary frontiers of contemporary technology. This field, which until a few years ago was considered mainly theoretical, is rapidly evolving towards concrete applications destined to redefine the landscape of computing, science, and society. This in-depth analysis offers a detailed examination of the fundamentals, potential, and challenges of quantum computing, highlighting its crucial role in overcoming the limits of classical computing and addressing problems of previously unimaginable complexity.

Technological frontiers: when miniaturization reaches its limits. For decades, Moore's Law [20] has guided the development of computing, predicting an exponential doubling of transistor density in microprocessors. Today, however, this incremental progress clashes with fundamental physical barriers. Transistors have reached dimensions on the order of 3-4 nanometers, and further reductions clash with the very principles of quantum physics. Miniaturization, which has fueled technological evolution for generations, is approaching its natural lower limit. The industry has responded to this challenge through massive chip parallelization, but this solution also shows evident limits in the face of the growing complexity of contemporary problems. The current reality is characterized by an exponential growth of data, with estimates indicating that by 2025 about 50% of the data produced will be generated by automatic systems. Although artificial intelligence has introduced a qualitative leap in the processing of enormous amounts of data, entire classes of problems remain unsolvable efficiently with traditional computational methods.

The complexity of contemporary problems. Natural, social, and technological phenomena are intrinsically nonlinear and complex. The most pressing global challenges - from the climate crisis to personalized medicine, from space exploration to the management of interconnected financial systems - require computational capabilities that radically exceed current ones. In this context, quantum computing emerges not as a simple evolution of the existing paradigm but as a radically different response to new computational needs.

From classical to quantum computing: a paradigm shift. The leap from classical to quantum computing does not represent a simple increase in computational power but a true paradigm shift in information processing. Traditional computers are based on the manipulation of bits that can only take the values "0" and "1." This binary dualism has been the theoretical and practical foundation of computing for over seventy years.

Quantum revolutions. The history of quantum physics can be read through two fundamental "revolutions." The first, at the beginning of the 20th century, allowed us to understand the structure of matter at the level of atoms, electrons, and photons. From this understanding emerged technologies that are now ubiquitous: microchips, lasers, magnetic resonances, nuclear power plants, GPS, and cell phones. The second quantum revolution, currently underway, focuses on the controlled manipulation of single particles and photons. This transition paves the way not only to new computational capabilities but also to extremely precise quantum sensors and intrinsically secure communications [21]. We are thus going beyond the binary in a completely new context, where physics reinvents computation.

CHAPTER 5

THE IMPACT OF QUANTUM COMPUTING ON INDUSTRIAL AND STRATEGIC SECTORS

The spread of quantum computing in industrial sectors. Quantum computing is rapidly moving out of research laboratories to enter the world of industry in various applications. According to the latest data, quantum computing is progressively emerging as a transformative technology in multiple industrial sectors, with applications that are thus moving from the purely theoretical phase to practical implementations. In 2024, there are a total of 303 quantum computing and quantum communication projects, carried out by 203 companies in various fields [22]. With a growth in private investments that already exceeded 1.7 billion dollars in 2021. This development is driven by the unique ability of qubits to process information exponentially faster than classical systems, enabling solutions for problems previously considered intractable [23]. Quantum computers, by exploiting the properties of quantum mechanics, offer exponentially superior computational capabilities compared to traditional computers, with application prospects ranging from process optimization to molecular simulation, from cybersecurity to advanced artificial intelligence.

Development and adoption status. Quantum computing is currently in a phase defined as "Noisy Intermediate-Scale Quantum" (NISQ), characterized by still imprecise hardware and results with structural limitations. Despite these technological challenges, interest and adoption of quantum computing are growing at a sustained pace. Globally, 65% of companies declare themselves ready to adopt quantum computing within the next two or three years, while only 21% admit not yet being prepared to exploit its benefits [24].

Investment trends in Italy and the world. According to the Quantum Readiness Report 2025 by QuEra Computing, a global growth of budgets dedicated to quantum computing of 20% is expected in 2025. In Italy, investments show a slightly lower but still significant increase, with a projected growth of 14% in the same period. This increase in investments is particularly notable considering the current global economic challenges and underscores the growing strategic importance attributed to this technology [25].

Leading industrial sectors. The financial sector leads the adoption of quantum computing, representing 27% of total investments in this technology. This primacy is not surprising, considering the high potential for application in crucial areas such as investment portfolio optimization, risk analysis, and fraud detection. In China, for example, major insurance groups like Ping An Insurance are collaborating with specialized startups like Origin Quantum to develop quantum financial algorithms capable of identifying fraudulent behaviors in the capital market. These algorithms provide rapid and accurate early warnings, allowing the avoidance of significant financial losses. Researchers have developed fraud detection models based on quantum neural networks, capable of identifying anomalous transfers and effectively recognizing complex money laundering transactions [26]. The chemical-pharmaceutical sector represents the second largest investor in quantum technologies, with 21% of total investments. The potential of quantum computing in molecular simulation is revolutionizing the process of discovery and development of new drugs, traditionally long and costly. Dompé Pharmaceuticals, for example, is working with E4 Computer Engineering on the MoSeGad project (MOlecular StructurE Generation And Docking with Quantum Computing), aimed at leveraging the unique potential of quantum computing in generating the three-dimensional structure of molecules and in "molecular docking" [27]. This approach could significantly accelerate the discovery of new drugs, allowing much more accurate molecular simulations compared to traditional computational methods. Quantum computing also offers new opportunities for personalized medicine, particularly in the analysis of clinical trials. Quantum machine learning could identify information that would remain undetectable with classical computing and improve the understanding of individual responses to treatments [28]. The automotive industry represents 12% of investments in quantum computing, with applications ranging from vehicle design to the development of new materials, from production process optimization to advanced logistics. According to a survey by Markets & Markets, the market for Quantum Computing applied to the automotive sector is expected to reach 5,203 million dollars by 2035. Companies like Daimler are already working with quantum processors to understand how this technology can advance the development of new materials for electric vehicle batteries and improve automotive manufacturing techniques. Quantum computing is contributing to the creation of a fully connected, intelligent, and sustainable mobility ecosystem, with specific applications in supply chain management and automotive logistics, enabling efficient warehouse management and minimizing transportation costs [29]. The energy sector, together with utilities and telecommunications, represents another 12% of investments in quantum computing. The applications in this field are particularly promising for the optimization of energy networks and the transition to renewable sources. PwC Italy, for example, has launched a project titled "Quantum Machine Learning in Energy & Utilities: time series forecasting and grid optimization," focused on developing advanced quantum machine learning solutions for energy network forecasting and optimization. In a context where the transition to sustainability, increasing energy demand, and efficient resource management are absolute priorities, the application of quantum technologies represents a potential turning point. In the energy sector, quantum computing could also catalyze the development of solar cells with efficiency exceeding 50% and new energy storage systems, significantly contributing to decarbonization goals [30].

Concrete applications and use cases. In the financial sector, one of the most promising applications of quantum computing concerns fraud detection. Models based on quantum neural networks can more accurately identify anomalous transactions and complex money laundering schemes. Companies like Origin Quantum are collaborating with major Chinese financial institutions, including China Construction Bank, to develop specific applications in this field. The optimization of investment portfolios represents another crucial application area, where quantum algorithms can simultaneously process a much larger number of variables compared to classical computers, leading to more efficient asset allocation strategies and potentially superior returns. Quantum computing is also revolutionizing the process of drug discovery and development thanks to its ability to simulate molecular processes with extreme precision. While classical computers must resort to approximations that limit the accuracy of simulations, quantum systems can model the behavior of electrons and molecules at the quantum level, offering a more detailed view of the interactions between drugs and biological organisms. Dompé Pharmaceuticals' MoSeGad project, ranked first among seven proposals admitted to the call of the Italian Center for Super Computing, is based on the study of two quantum algorithms: the first for generating the three-dimensional structure of the molecule, the second for molecular docking. This approach could lead to the design of more effective drugs and the discovery of treatments currently beyond the reach of traditional computational technologies. In the manufacturing sector, quantum computing offers significant potential for optimizing production processes and the supply chain. Quantum computers can simulate the interactions of components within complex machinery, calculating more precisely and completely the system loads, assembly paths, noise, and vibrations. Aveva, a company specializing in industrial software, has recently announced a partnership with Oxford Quantum Circuits to develop a quantum computing application for the industrial sector. The goal is to exponentially speed up business operations, helping to reduce costs and energy consumption, including those related to large-scale AI language models and big data. In the logistics and transportation sector, quantum computing can optimize transport routes, reducing delivery times and costs, with a potentially revolutionary impact on the management of global supply chains. Finally, the application of quantum computing in the energy sector focuses mainly on the optimization of electrical networks and consumption forecasting. PwC Italy is developing a quantum machine learning algorithm suitable for various forecasting (prediction), generation, and energy load applications on the network. These solutions could significantly improve the accuracy of forecasts and optimize the management of energy networks, with a direct impact on decarbonization and operational efficiency. The algorithm is designed to be integrable and usable in a real IT infrastructure [31], through hybrid methodologies that combine conventional and quantum hardware.

Challenges and barriers to adoption. Despite growing interest and increasing investments, the adoption of quantum computing still needs to overcome significant obstacles. Globally, high costs represent the main barrier, reported by 51% of respondents in the Quantum Readiness Report 2025 [32]. In Italy, the biggest problem concerns limited access to quantum hardware. The current NISQ phase is characterized by imprecise hardware and results, with structural limitations related to qubit instability, making systems susceptible to noise and errors. Furthermore, the immaturity of quantum algorithms represents an additional challenge for the implementation of effective solutions. The shortage of qualified talent in the field of quantum computing is a global problem, indicated as one of the main obstacles to adoption. This challenge is particularly relevant considering the highly specialized nature of this emerging technology and the need for interdisciplinary skills that combine quantum physics, computer science, and specific knowledge of application sectors. In Italy, the lack of a qualified workforce is considered a notable obstacle. To overcome this barrier, it will be necessary to invest in training and talent attraction, as well as in the development of collaborations between universities, research centers, and industry. The integration of quantum solutions with existing IT infrastructures represents another significant challenge. Companies will need to develop hybrid approaches that combine conventional and quantum hardware, ensuring scalability and operational continuity. PwC Italy, for example, is paying particular attention to this aspect in its quantum machine learning project for the energy sector, designing algorithms that are integrable and usable in a real IT infrastructure through hybrid methodologies that combine conventional and quantum hardware [33].

Future prospects and recommendations. The future of quantum computing will depend on the ability to overcome current technological limitations and develop increasingly advanced hardware and software. According to experts, a hundred logical qubits would already be sufficient for some specific applications, such as drug discovery, which could represent the first "killer app" of quantum computing [34]. In the coming years, we expect a progressive improvement in the performance and reliability of quantum computers, with a reduction in costs and an expansion of possible applications. The combination of quantum computing and machine learning, as well as its application to optimization, will likely have a significant impact in various industrial sectors, from manufacturing to finance, from pharmaceuticals to energy. To fully exploit the potential of quantum computing, companies should adopt a strategic approach that includes: identifying specific use cases where quantum computing can offer a concrete advantage over traditional technologies; developing collaborations with universities, research centers, and specialized companies to access skills and infrastructures that would otherwise be difficult to obtain; investing in training and attracting talent with skills in quantum computing and its sectoral applications; adopting hybrid approaches that combine quantum and classical technologies, ensuring integration with existing systems and operational continuity; participating in collaborative projects and initiatives, such as those funded through the PNRR and other national and European research programs. Quantum computing represents a potentially disruptive technology, destined to transform numerous industrial sectors in the coming years. Companies that can anticipate this transformation, investing today in research, experimentation, and skill development, could gain a significant competitive advantage in the medium to long term.

CHAPTER 6

THE GLOBAL RACE FOR QUANTUM SUPREMACY

Strategies, investments, and prospects. Quantum computing is establishing itself as one of the most disruptive technologies of the 21st century, capable of redefining global geopolitical and economic balances. This advanced technology has triggered an unprecedented race among the world's major powers, with over 40 billion dollars in public funding allocated internationally. China leads this competition with 15.3 billion dollars invested, followed by the United States (1.2 billion) and the European Union (1 billion euros). The expected economic impact is extraordinary: it is estimated to exceed 1.3 trillion dollars by 2035, revolutionizing key sectors of the economy.

The geopolitics of quantum computing. China has elevated quantum computing to a fundamental pillar of its national security policy, adopting an integrated approach that involves academia, industry, and defense. The investment of 15.3 billion dollars has led to concrete results, including the creation of the first national production line of quantum chips and the launch of the "Origin Wukong" computer in January 2024, representing the third generation of advanced systems. This initiative fits perfectly within the "2025 Plan," the Chinese strategy for global technological leadership, where quantum supremacy is considered a strategic tool for decrypting foreign communications and protecting national critical infrastructures. The United States has adopted a different strategy, based on synergies between research centers and the private sector. With a public investment of 1.2 billion dollars distributed across 5 main research centers, in 2022 they held 37% of global patents in quantum computing, equivalent to 1,344 registrations. The American focus is mainly on cryptographic applications and financial simulations. However, the 3% drop in global investments in "venture capital," recorded in 2024, raises questions about the long-term sustainability of this model. Other nations are also entering this technological competition. Japan, with the Quantum Leap Flagship Program (QLFP), is aiming for hybridization between quantum technologies and artificial intelligence, with the goal of optimizing supply chains. India has launched a national mission worth 1 billion dollars (2023-2028) focused on post-quantum cryptography and advanced sensing [35]. The United Arab Emirates, as part of the "UAE Centennial 2071" strategy, have developed partnerships with European companies to implement quantum algorithms in energy management.

The European strategy in quantum computing. Europe is positioning quantum technologies as a pillar of its technological sovereignty, through a multi-level approach that combines research, infrastructure, and transnational collaboration. In 2018, the European Union launched the "Quantum Flagship," a ten-year program worth 1 billion euros, structured around four strategic pillars: quantum computing, quantum communication, quantum simulation, and the development of quantum sensors for environmental and geological applications. In 2022, the EU selected six countries (Czech Republic, Germany, Spain, France, Italy, and Poland) to host the first European quantum computers, with a total investment of 100 million euros, equally funded by the EU and member states. These systems will be interconnected with EuroHPC supercomputers, forming a hybrid network accessible via cloud for non-commercial research [36]. A fundamental element of the European strategy is the European Quantum Communication Infrastructure (EuroQCI), designed to protect the sensitive data of public institutions and critical infrastructures in the energy and health sectors. The infrastructure includes terrestrial fiber optic networks with quantum cryptography protocols and a space segment based on satellites, which will be integrated into the future EU IRIS system. Significant experiments are already underway in the Netherlands (Amsterdam-Delft route) and Italy (Frejus-Matera route), with funding of 90 million euros [37].

Specialized training and technological development. The Quantum Flagship has set ambitious goals in terms of human capital development, aiming to create a network of 5,000 specialized researchers by 2030. This goal responds to the need to bridge the skills gap that separates Europe from competitors like China and the United States. On the technological front, the EU has set itself the goal of launching the first supercomputer with quantum acceleration by 2025, integrating it into the "Euro QC!" cloud infrastructure for non-commercial applications in strategic sectors such as pharmacology and logistics. Another significant step is represented by the regulation on low-cost quantum chips, approved in 2023, which aims to strengthen European production autonomy in this critical sector.

Structural criticalities and systemic challenges. Despite efforts, Europe must face several structural criticalities that risk compromising the effectiveness of its quantum strategy. A first issue concerns the fragmentation of investments: 72% of funding in the sector still comes from public funds, with uneven distribution among member states, while only 28% comes from private investors, a percentage significantly lower than the 50% recorded in the United States. Particularly concerning are the technological dependencies: Europe is forced to import critical components such as cryostats and photon detectors, exposing it to potential geopolitical risks.

European coordination and standardization harmonization. One of the most complex challenges lies in the need to strengthen coordination at the European level, currently threatened by the tendency of some member states, particularly Germany and France, to develop autonomous programs in the quantum sector. This fragmentation risks reducing the overall effectiveness of community efforts, dispersing precious resources. Another critical area concerns the lack of common protocols for post-quantum cryptography, essential elements to ensure the interoperability and security of future communication networks. Despite these difficulties, the EU maintains the ambitious goal of achieving "Quantum Advantage" by 2025 in specific sectors such as logistics, pharmacology, and energy. In this context, the European delay in commercial applications is evident: the United States holds 37% of global patents in the sector, while the EU stands at 22%.

The "Third Way" European. Europe is trying to develop its own distinctive model, a "Third Way" that differs from both the Chinese state approach and the American private one. This model is based mainly on two pillars: transnational collaboration, exemplified by the Quantum Flagship and the EuroHPC initiative, and the pursuit of technological sovereignty, supported by initiatives such as the European production of low-cost quantum chips and the EU regulation on semiconductors. Although Europe has a dynamic quantum ecosystem, to compete on equal terms with other powers, it must overcome three fundamental obstacles: the integration between research and industry, the reduction of external dependencies through the enhancement of critical component production, and the acceleration in the adoption of post-quantum cryptographic standards to protect strategic infrastructures.

Infrastructures and experiments on Italian territory. Italy is at a crucial moment for the development of quantum technologies. Despite an initial delay compared to other European countries, the country is making significant strides to build a national ecosystem in the field of quantum computing, with targeted investments and ambitious projects like Euro QCS Italy and QUID [38]. Future success will depend on the ability to overcome current challenges, particularly the need for greater public and private investments and the development of a complete national value chain. An integrated approach between the academic, industrial, and institutional worlds will be fundamental, as highlighted by Professor Tommaso Calarco, coordinator of the working group for the National Strategy: "It will be essential to follow in the footsteps of the European approach already marked years ago, i.e., to integrate the world of research with that of industry." With Euro QCS Italy and IQM Radiance [39], Italy is positioning itself at the forefront of European quantum computing, creating the conditions for the Italian scientific community and companies to take a leadership role in this strategic sector. However, to consolidate this position, continuous and coordinated commitment from all involved actors will be necessary, with a long-term strategic vision and adequate resources to compete globally [40]. A tangible sign of Italy's involvement in European quantum initiatives is represented by the selection of Italy among the six countries destined to host the first European quantum computers, as part of the program launched in 2022. Furthermore, Italy actively participates in the experiments of the European Quantum Communication Infrastructure (Euro QCI), with a pilot project covering the Frejus-Matera route. These initiatives demonstrate not only Italy's contribution to European quantum infrastructures but also the presence of skills and technical capabilities on the national territory able to support the development of these advanced technologies [41].

CHAPTER 7

ETHICAL ISSUES AND SOCIAL IMPLICATIONS

Inequalities and access to technology. Limited access to quantum technology could widen the economic and technological gap between countries and institutions, creating new forms of inequality on a global scale. The pervasiveness of quantum computing could accentuate inequalities between those who have access to quantum technologies and those who are excluded. Companies and countries that invest first in the formation of quantum skills and the adoption of advanced infrastructures will have a significant competitive advantage but risk widening the gap between digital and social. It will be essential to promote policies of inclusion, training, and equitable access to quantum technologies, avoiding that the quantum revolution becomes a factor of exclusion or marginalization for large segments of the population. In short, ensuring the most equitable possible distribution of the benefits derived from progress [42].

Privacy, surveillance, and individual freedom. The acceleration of computational processes and the ability to process enormous amounts of data, enabled by quantum computers, could generate problems related to privacy and the security of personal information. In particular, the risk of large-scale surveillance and control would increase, with potential implications for individual rights and civil liberties, if these technologies are not managed responsibly. It will be necessary to develop new regulatory frameworks and governance tools to balance the needs of security, innovation, and the protection of fundamental rights, promoting an ethical and responsible use of quantum technologies [43].

Opportunities in cybersecurity. Despite the threats to traditional cryptographic systems, quantum computing offers significant opportunities to improve cybersecurity. Advances in quantum machine learning could drastically reduce the profile of cyber threats and improve latency in reducing vulnerabilities. Furthermore, improvements in operational research algorithms could lead to faster methods of updating, repairing, and verifying systems, reducing the time windows available for potential attacks.

Responsibility, governance, and complex decisions. The automation of complex decision-making processes through quantum algorithms and Artificial Intelligence raises issues of responsibility and transparency. Who will be responsible for decisions made by autonomous quantum systems? How to ensure that choices are fair, transparent, and respectful of human values? The governance of quantum technologies will have to be multi-level, involving governments, companies, civil society, and the scientific community, to define rules, standards, and control mechanisms that ensure a balance between innovation, security, and individual rights [44].

Philosophical interpretations and new worldviews. The pervasiveness of quantum computing could also influence our view of reality and knowledge. Interpretations of quantum mechanics, such as the "Many Worlds Interpretation," suggest that every decision or event could generate parallel universes, opening unprecedented philosophical and cultural scenarios. The ability to simulate alternative worlds and explore multiple possibilities simultaneously could transform our way of thinking about the future, causality, and individual responsibility [45].

CHAPTER 8

CHALLENGES, INNOVATIONS, MARKET: POSSIBLE FUTURES

The market for quantum technologies: overview and trends. The field of quantum technologies is experiencing a moment of extraordinary momentum, with the potential for radical transformation in multiple industrial and scientific sectors. Taking stock of the current state of quantum technologies, technical challenges, emerging applications, and future prospects is important to understand the evolution of a sector that promises to revolutionize our approach to computing, cybersecurity, and scientific research. According to the "McKinsey Digital Quantum Technology Monitor 2024," the market for quantum technologies is registering strong growth in three main areas: quantum computing, quantum sensing, and quantum communication. Projections for 2035 indicate considerable growth in all these sectors, with quantum computing leading economic development. The market size is expected to reach impressive figures by 2035; it is estimated that quantum computing could go from 28 to 72 billion dollars, quantum communication from 11 to 15 billion dollars, quantum sensing from 0.5 to 2.7 billion dollars. By 2035-2040, a cumulative contribution of 1-2 trillion to global GDP is expected, driven by sectors such as finance, defense, and pharmaceuticals.

Despite the considerable growth potential, private and corporate funding for startups in the quantum sector has recently experienced a decline, albeit less marked, compared to the 38% drop in overall global startup funding in 2023. This slowdown is probably attributable to macroeconomic factors such as inflation, high interest rates, and geopolitical uncertainty.

Trends in investments. An interesting phenomenon concerns the maturation of the quantum startup ecosystem: 62% of funding went to companies founded five or more years ago, highlighting a shift in investments towards more established and promising realities, with particular attention to their scalability. Contrary to the private sector, public investments have increased by over 50% compared to 2022. Numerous countries, with Germany, the United Kingdom, and South Korea at the forefront, have announced significant funding for the development of quantum technologies, bringing the total of global public funding to about 42 billion dollars. The potential economic impact of these technologies is extraordinary. According to forecasts, they could generate up to 2 trillion dollars by 2035, with particularly significant effects in sectors such as chemistry, life sciences, finance, and mobility [46].

Technological innovations: topological qubits. One of the most promising developments in the field of quantum computing concerns topological qubits, which represent a fundamentally different approach compared to traditional qubits. These qubits exploit the principles of mathematical topology, i.e., they focus on the study of properties that remain unchanged in the presence of continuous deformations. Topological qubits offer several significant advantages: greater stability and resistance to errors; intrinsic protection from local perturbations; maintenance of stable quantum states under different conditions; better scalability for longer and more complex calculations. Microsoft is at the forefront of developing this technology through its research center Station Q. The company has recently announced important discoveries, demonstrating the possibility of producing topological qubits, confirming the validity of the underlying theory. Although engineering challenges remain, this discovery represents a fundamental element for the realization of large-scale topological quantum computers.

The development of topological quantum computing has attracted the attention of major technology companies and research institutes worldwide. In addition to Microsoft, Google, through its AI division, is exploring complementary approaches. These efforts are joined by academic collaborations and government-funded programs worldwide, highlighting the strategic importance of this technology [47].

Towards a new era of cybersecurity: the challenge of post-quantum cryptography. One of the most significant implications of the advent of quantum computers concerns cybersecurity, particularly cryptography. The current digital security infrastructure is largely based on cryptographic algorithms that require, to be decrypted, a speed and computational complexity that traditional computers do not possess. Many cryptographic systems are based on mathematical problems such as the prime factorization of very large numbers, which represent an insurmountable obstacle for traditional computers. However, since 1994, well before functional quantum computers existed, there have already been quantum algorithms capable of performing prime factorization and other cryptographic operations in drastically reduced times. Asymmetric key algorithms like RSA, widely used for portal authentication, digital signatures, and many other security areas, could become vulnerable with the advent of sufficiently powerful quantum computers. Aware of this potential threat, various governments and organizations are developing "Quantum Safe" algorithms, designed to resist quantum attacks. The United States, through the National Institute of Standards and Technology (NIST), launched a call in 2016 to select new post-quantum cryptography standards. In 2022, four certified algorithms were identified, and in the summer of 2024, usage standards were released for three of these algorithms. This race to develop new cryptographic solutions highlights the urgency of preparing for the quantum era, anticipating potential vulnerabilities before they become concrete problems. Quantum computing represents a substantial threat to current cryptographic systems. Quantum computers could completely compromise them, particularly public-key cryptography, while having more limited (but still significant) impacts on symmetric algorithms like AES [48]. Today's cryptographic algorithms, robust against attacks from classical computers, would become highly vulnerable in the face of quantum computing power. Mathematician Peter Shor has demonstrated how a quantum computer could efficiently factor the products of large prime numbers, thus undermining the security of protocols like RSA [49]. Experts predict that by 2031, quantum computers will be able to break one of the most used algorithms, RSA-2048, which protects SSL and TLS security protocols for Internet communications [50]. In the event of a compromise of current cryptographic systems, credit card transactions and stock exchanges could be invaded by scammers and cybercriminals, air traffic systems and GPS signals could be manipulated, the security of critical infrastructures like nuclear power plants and the electrical grid could be compromised, sensitive information such as military secrets, weapon designs, and industrial secrets would become vulnerable. A particularly insidious danger is that even previously encrypted data could be decrypted after the so-called "Q-Day" (the day when quantum computers become sufficiently powerful) [51].

The future spread of quantum computers. Unlike traditional computers, which followed Bill Gates' prediction of "a computer on every desk and one in every home," the spread of quantum computers will likely follow a different path, at least in the short term. Current quantum computers have characteristics that limit their widespread distribution: considerable dimensions, not so much for the processor itself, but for the complex cryogenic cooling systems required; the need for extremely precise and stable optical benches; rapid technological evolution, which quickly makes existing models obsolete. Currently, quantum computers are mainly accessible via cloud, allowing users to benefit from continuous technological updates without having to physically purchase the machines. This mode of use will likely remain dominant even in the medium term. In a 10-30 year perspective, we might see an evolution similar to that of traditional computers, with significant technological leaps in miniaturization and a progressive reduction in production costs. If processors capable of guaranteeing a quantum advantage (Quantum Advantage) in specific areas are achieved, we might see the emergence of dedicated production lines that would make these technologies accessible to a wider audience.

CHAPTER 9

THE EMERGENCE OF QUANTUM COMPUTING PROFESSIONS

The emerging professional ecosystem. By 2030, the creation of 250,000 specialized jobs in quantum engineering, algorithm development, and cybersecurity is expected, with a growth of 840,000 units by 2035 [52].

These projections are based on the analysis of the economic impact of quantum computing on the global economy between 2025 and 2035. However, these forecasts should be taken with due caution, as the sector is characterized by high unpredictability. The rapid evolution of this field will nevertheless require specialized figures both in technological development and in the implementation of quantum solutions in the business context, requiring a profound rethinking of skills and professional training in Italy and the world [53]. The quantum revolution does not represent merely an incremental evolution of existing technologies but a paradigmatic change that requires radically new skills. As effectively illustrated by Federico Mattei (Quantum Business Developer at IBM): "It's like comparing a car, a train, and an airplane; all serve to move, but they operate according to different physical principles and require very different skills." A classical computer programmer cannot be easily converted into a quantum programmer, just as a train driver cannot automatically become an airplane pilot. In the coming years, the birth of an Italian ecosystem dedicated to these technologies is expected, which will constitute a new sector, with a significant impact from an economic, occupational, and national security perspective. This development will require a new workforce composed of both specialists dedicated to technology development (from hardware to software) and company personnel capable of using them and guiding their introduction [54].

Professions in quantum hardware. In the field of quantum hardware, essential professional figures are emerging for the development of the physical architectures of quantum computers. These professions require a deep understanding of the principles of quantum mechanics and their technological applications. The quantum engineer primarily deals with the development of the hardware architectures of quantum computers and quantum sensors. Their responsibilities include the design and construction of quantum hardware, the coding of associated software, and the conduction of experiments to test and refine systems. Quantum engineers must tackle complex challenges such as reducing calculation errors and developing error correction strategies. The quantum physicist represents another fundamental figure, indispensable for examining the foundations of the software and hardware of quantum computers and for optimizing all possible applications of the quantum industry. Thanks to a deep understanding of quantum mechanics, this professional figure contributes to research and technological development in this sector. Quantum physicists are essential in solving problems related to quantum coherence and noise reduction [55].

Professions in quantum software. On the software side, highly specialized figures are also emerging, requiring specific skills substantially different from classical programming. Quantum software engineers are difficult-to-find and therefore highly sought-after professionals dedicated to creating software used to develop extremely complex quantum computers. Their rarity stems from the fact that quantum programming differs substantially from classical programming and requires specific skills in quantum information theory and a solid mastery of linear algebra. Quantum computer scientists adopt a more experimental approach, using quantum theory to conduct experiments aimed at finding and testing solutions to complex problems. This figure designs experiments, verifies hypotheses, and analyzes results to better understand the applications of quantum computers. Their responsibilities include developing specific quantum algorithms for complex computational problems and creating quantum simulations to verify theories. Quantum software specialists are particularly needed by companies operating in the security and cryptography sectors, such as finance and cybersecurity. These professionals deal with the optimization of quantum circuits to improve performance and reduce computational errors, as well as developing and implementing error correction and mitigation techniques for quantum calculations. Quantum developers are more focused on the technical aspects and deal with developing quantum software based on existing projects. These professionals must possess programming skills in languages such as

Python and C++, with a deep understanding of quantum frameworks like Qiskit [56].

Strategic and business roles. In addition to technical figures, strategic roles crucial for guiding the integration of quantum technologies into business contexts are emerging. We are talking about "Quantum Business Strategists," who are profiles with solid technical foundations capable of guiding the introduction of quantum technologies within organizations. These professionals represent the bridge between the technical and business worlds, facilitating the integration of quantum technologies into business processes. As highlighted by the discussion on skills in the field of quantum technologies, there are three fundamental aspects to develop: fundamental physics, quantum hardware, and its impact on business processes. This tripartition reflects the need for a multidisciplinary approach that integrates theoretical knowledge, technical skills, and strategic vision [57].

Required skills and training challenges. The quantum revolution thus requires skills that are radically new compared to those required in traditional computing. One of the most pressing challenges concerns the availability of specialized skills, as highlighted by the provocative statement: if today an alien civilization arrived and gave us a quantum computer with 9 billion qubits, probably no one would know what to do with it. This statement highlights a real problem: the scarcity of professionals capable of programming these systems. Only 12% of Italian companies have dedicated teams, compared to 34% in Germany. Quantum computer programmers are still extremely rare, as a quantum computer is not simply an accelerator for existing algorithms but a tool that operates according to completely different principles. To compete effectively in this emerging sector, it is necessary to develop skills in three fundamental areas: Fundamental physics, with particular attention to quantum mechanics; Quantum hardware and its implementation; Integration into business processes and business strategy. The development of specialized skills in this field constitutes a priority challenge for the educational system and for companies intending to exploit the potential of these technologies. For Italy, the development of skills in this sector represents a strategic opportunity to position itself favorably in the innovation economy of the next decade. Investing in the training of qualified professionals in quantum computing could significantly contribute to the country's competitiveness in a technological area destined to grow in importance in the coming years. The dual challenge of hardware and software development in quantum computing will require an integrated and multidisciplinary approach, in which technical skills, strategic vision, and innovation capabilities must combine to realize the full potential of this revolutionary technology. Despite the technical challenges still to be overcome, the field offers exciting prospects both for research and commercial applications, creating a new professional paradigm that requires specific training and continuous skill updating.

Educational ecosystem and learning tools. The educational ecosystem related to quantum computing has seen significant expansion in recent years. Training in this emerging sector is rapidly evolving to meet the growing demand for specialized skills. There is an increasing need for hybrid programs (physics-computer science) and technical certifications (e.g., Qiskit, IBM Quantum). Meanwhile, alongside the development of funding, there has been a significant increase in the training offer, with numerous universities establishing specific programs and master's degrees in quantum technologies. The European Union and the United Kingdom boast the highest number and density of graduates in this field, respectively, highlighting a growing investment in the human capital necessary to sustain this technological revolution. At the international level, 61 first and second-level master's degrees have been activated, of which about ten are also present in Italy [58]. Despite these steps forward, Italy is still in the initial phase of this training process, and much remains to be done to build a competitive ecosystem at the international level. Collaboration between universities, research centers, and companies is fundamental to develop effective training paths aligned with market needs [59].

Career opportunities. Career opportunities in the field of quantum computing are multiplying, thanks to the expansion of application areas for this technology. Sectors such as Banking & Finance, Cybersecurity, Machine Learning, Healthcare, Transportation, medical research, environmental and energy sectors are progressively integrating quantum computing technologies into their operations. The figure of the quantum computing expert, in its various forms [60], is increasingly sought after and well-remunerated. In the United States, for example, the average salary of a quantum computing expert amounts to about 86,000 dollars per year, equivalent to about 7,000 dollars per month.

Challenges for sector development. A fundamental challenge concerns the ability of companies to identify which applications in their ecosystem could benefit from quantum computing. It is essential to distinguish between applications that could work with relatively small and still error-prone quantum computers and those that will require much more powerful machines, available only in a longer time horizon. Companies must begin to select the algorithms from which an immediate advantage is expected -

those that Americans call "low-hanging fruits" - and rethink them in a quantum key, so that they are ready when quantum computers become sufficiently powerful and reliable. On the technological front, significant challenges remain, such as quantum decoherence and the need to develop effective error correction mechanisms, fundamental aspects for the refinement of quantum systems and their application in real contexts [61].

Accessibility and democratization of knowledge. Contrary to what might have been thought in previous years, particularly before 2016, access to this sector has undergone significant democratization. If in the past, specialized training in quantum mechanics or theoretical physics was an almost indispensable prerequisite, today the barriers to entry have been significantly reduced.

This phenomenon has led to a substantial expansion of the pool of professionals potentially involved in the sector. A particularly relevant element in the evolution of this field is the progressive accessibility of the necessary knowledge. Professionals from seemingly distant fields such as traditional computer science or risk management in the banking sector can now undertake specific training paths to integrate their skills with those necessary for understanding and applying quantum algorithms in their reference sector. This democratization process is supported by the increasing availability of training and application tools, many of which are distributed with open-source licenses, facilitating both theoretical learning and practical experimentation with quantum technologies. A fundamental aspect of this evolution is the possibility of freely accessing practical programming tools. The availability of intuitive graphical interfaces based on drag-and-drop mechanisms [62] makes these tools accessible even to high school students, facilitating a first approach to the sector. At the same time, more advanced tools based on widely used programming languages like Python allow anyone with basic computer skills to concretely experiment with quantum computing. It is important to emphasize that this accessibility is not limited to the use of simulators but also includes the possibility of interacting with real quantum hardware.

The role of new generations and temporal perspectives. At this historical juncture, it is mainly the young who fully understand the revolutionary scope of this technological transformation. The new generations, although having grown up in an era characterized by seemingly consolidated technology, show significant enthusiasm for the possibility of actively participating in a new technological revolution. Temporal forecasts, despite the inevitable uncertainties inherent in technological innovation processes, indicate a relatively short consolidation horizon. This timing is particularly favorable for those currently training in this field, as it could coincide with the completion of their training path and entry into a market characterized by a very high demand for quantum programmers, similar to what is observed today for professional figures such as data scientists and cybersecurity experts. The relatively close temporal perspectives make this sector particularly attractive for young people in training, configuring it in the medium term as a field with high occupational potential. The availability of accessible training and application tools constitutes a facilitating element, which could further accelerate the spread of these skills and the expansion of the sector [63].

CHAPTER 10

AN IMMINENT FUTURE?

Living in a quantum world: a journey between present and future. Advances in the field of quantum computing are bringing humanity closer to one of the greatest technological revolutions in history. The emergence of sufficiently powerful quantum computers will represent not a simple incremental step but a giant leap that will make traditional supercomputers obsolete [64]. Quantum physics represents one of the deepest paradigmatic changes in the history of science, whose applications are progressively transforming our way of living, working, and even thinking. This phenomenon develops along two fundamental lines: on one hand, quantum technologies already integrated into our daily lives, often without our full awareness; on the other, the imminent "second quantum revolution" that promises to redefine numerous aspects of contemporary society, from medicine to cybersecurity, from artificial intelligence to transportation. The quantum world is already influencing our lives and will continue to transform them in the near future, outlining a panorama of innovations that transcend mere technological evolution to embrace new conceptions of reality [65].

Quantum physics in our daily lives. Contrary to what many might believe, we do not have to wait for the future to experience the effects of quantum physics. We already live immersed in a world permeated by technologies that exploit fundamental quantum principles. These innovations constitute what scientists have defined as the "first quantum revolution," a phenomenon that has silently but profoundly changed contemporary society.

Everyday technologies of quantum origin. If we look around, we can identify numerous devices that would not exist without the understanding of quantum principles. The laser, for example, invented in the 1960s and now ubiquitous in our daily lives, represents one of the most evident applications of quantum physics. This technology, based on stimulated emission of radiation, has found use in surprisingly diversified contexts: from reading barcodes in supermarkets to precision surgical interventions, from fiber optic communications to industrial production. Common electric light bulbs, chips inside our computers and smartphones, magnetic resonance machines in hospitals - all these devices are concrete examples of how the quantum theory developed in the early 20th century has produced technologies that we now take for granted. Transistors, fundamental components of any modern electronic device, function thanks to quantum principles such as the tunnel effect and the wave-particle duality [66].

The first quantum revolution: foundations of the modern world. The first quantum revolution laid the theoretical and technological foundations of the digital world in which we live today. During this phase, scientists managed to understand and exploit the collective behaviors of quantum particles, creating materials and devices with extraordinary properties. Semiconductors, cornerstones of modern electronics, are perhaps the most emblematic example of this process. This revolution, which began in the first decades of the 20th century with the pioneering works of physicists such as Max Planck, Albert Einstein, Niels Bohr, and Erwin Schrödinger, gradually transformed our understanding of matter and energy, providing explanations for phenomena that classical physics could not justify. From photovoltaic cells to LEDs, from superconductors to medical imaging devices, the practical applications of quantum theory have reshaped the contemporary technological landscape in ways that the first theorists could barely imagine.

The second quantum revolution: a new horizon. If the first quantum revolution exploited the general principles of the theory to create new materials and devices, the second quantum revolution, now in its infancy, is distinguished by a significantly different approach. This new phase focuses on the use and manipulation of individual quantum objects - atoms, photons, electrons - to develop revolutionary tools for computation, perception, and communication [67].

A profound social transformation. The second quantum revolution does not represent merely a technological advancement but is configured as a transformation destined to reshape the entire society, profoundly influencing our ways of living and working. This revolution promises to redefine crucial sectors such as medicine, energy, cybersecurity, and transportation, creating new industries and radically modifying existing ones. The potential impact of technologies like quantum computing has been compared to that of smartphones in the decade preceding the 2020s. Just as mobile devices have radically transformed the way we communicate, work, and access information, quantum computers could represent a similar technological turning point, with equally profound implications for society.

Emerging quantum technologies. At the center of this revolution are several interconnected technologies that exploit the most peculiar properties of quantum mechanics, such as the principle of superposition, entanglement, and quantum tunneling. Quantum computers, in particular, represent perhaps the most promising and discussed innovation. These devices, instead of processing information through binary bits (0 and 1), use qubits, which can exist simultaneously in both states, theoretically allowing the resolution of problems currently intractable even for the most powerful supercomputers. Other emerging technologies include extremely precise quantum sensors, quantum simulators for modeling complex systems such as new materials or chemical reactions, and quantum communication networks, which promise theoretically unbreakable levels of security. These innovations are not simple incremental improvements of existing technologies but radically new approaches that exploit previously unused physical laws.

How daily life will change. The impact of quantum technologies on daily life will likely be multifaceted and pervasive, although not always immediately visible to the end user. The most significant benefits will probably manifest in crucial sectors such as health, artificial intelligence, and security, with indirect but profound repercussions on the quality of daily life.

Health and personalized medicine. In the medical field, quantum technologies promise to revolutionize several aspects, from diagnosis to therapy. Thanks to the quantum analysis of clinical data, it will be possible to make much earlier diagnoses of complex pathologies, intercepting signals that current diagnostic tools cannot detect. This approach could radically transform the healthcare paradigm, shifting the emphasis from cure to prevention. Personalized medicine represents another area where quantum computing could have a decisive impact. The development of tailor-made drugs, based on individual DNA, currently limited by prohibitive costs and long times, could become a standard practice thanks to the molecular simulation capabilities of quantum computers. Complex diseases such as Alzheimer's and various forms of cancer, which require the analysis of enormous amounts of data and biomolecular interactions, could benefit from completely new therapeutic approaches, developed thanks to quantum computing capabilities.

Technology and artificial intelligence. Artificial intelligence, already rapidly evolving, could undergo further acceleration thanks to integration with quantum technologies. The relationship between quantum computing and AI operates in a bidirectional manner: quantum computers enhance AI algorithms by improving their capabilities and efficiency, while AI optimizes the development of quantum computing, creating a virtuous circle of mutual advancement. A fundamental element is the process of "Transpilation" [68] that AI can significantly optimize through machine learning techniques, identifying strategies that would be difficult to determine manually. There are already AI-based programming assistants that support developers in writing complex quantum algorithms, democratizing access to this advanced technology. In machine learning, quantum systems can accelerate the training of complex models and optimize existing algorithms, allowing the tackling of computationally prohibitive problems for classical systems, having the ability to process massive datasets and solve complex problems in reduced times. This enhancement would result in more reliable predictions in diverse fields such as diagnostic medicine and finance, where the ability to rapidly process large amounts of data represents a fundamental competitive advantage. Autonomous systems, from industrial robots to self-driving cars, would become significantly more intelligent, capable of faster decisions. However, there are significant risks: AI enhanced by quantum capabilities could amplify cybersecurity issues, while increased quantum computing power could compromise current cryptographic systems. This requires the urgent development of post-quantum cryptography and a balanced approach that maximizes benefits while minimizing risks through adequate governance and continuous research on ethical and security aspects. Only through interdisciplinary collaboration will it be possible to realize the transformative potential of this technological synergy, ensuring widespread benefits and mitigated risks [69].

Daily life. Although it is unlikely that in the near future we will use home quantum computers - these devices are indeed destined to solve very complex problems, not to send and receive emails - the effects of these technologies will still be felt in the daily life of each of us. The most immediate impact will concern digital security, with new quantum cryptography protocols that will make communications and online transactions more secure. Other effects could include more accurate weather forecasts, optimized public transport systems, and new materials with extraordinary properties, developed thanks to quantum simulations. Even if invisible to the end user, these improvements would have concrete repercussions on the quality of daily life, from energy efficiency to environmental sustainability.

Towards a new philosophy of life? Beyond the purely technological aspects, some scholars suggest that the principles of quantum mechanics could also inspire a new way of thinking and conceiving reality, potentially influencing the philosophical sphere and human relationships. We might ask ourselves what the consequences would be of applying quantum theory not only to technology but also to our daily lives and our way of reasoning. Moving from classical logic, which has characterized our world until now, to a "quantum logic" could put us in greater harmony with the intimate reality of the Universe. This conceptual transition would imply the acceptance of principles such as the superposition of states and complementarity, challenging our classical intuitions of linearity and determinism.

Quantum metaphors for personal growth. Some authors have begun to explore quantum physics as "a collection of metaphors" capable of inspiring "reflections that go beyond the external and material plane of reality and instead concern the inner, individual, and relational sphere." Concepts such as "quantum entanglement," which describes how separated particles can remain connected regardless of distance, offer powerful analogies for exploring human relationships and the interconnectedness between individuals in an increasingly complex and globalized society. This perspective, although speculative, suggests that the quantum revolution could have implications that transcend the technological realm, potentially also influencing how we conceive of ourselves and our relationships with others and the surrounding environment.

Preparing for a quantum future. The quantum world is not simply a future prospect to await but a reality already in development that is progressively permeating numerous aspects of our existence. The first quantum revolution has already profoundly transformed contemporary society through technologies we now take for granted, while the second quantum revolution promises even more radical and pervasive changes. Preparing for this future requires not only investments in research and technological development but also an educational and cultural effort to understand the fundamental principles of quantum physics and their implications. The training of new professionals with interdisciplinary skills, capable of navigating between physics, computer science, engineering, and medical sciences, will become crucial to fully seize the opportunities offered by this technological revolution. The quantum world that is taking shape promises to profoundly transform many aspects of our existence - from health to technology, from security to environmental sustainability - offering innovative solutions to problems that today seem intractable. At the same time, it invites us to reconsider some of our most deeply held beliefs about the nature of reality, suggesting that we may be only at the beginning of an intellectual and technological journey that will redefine our place in the universe.

Beyond current limits. Recent discoveries, such as Microsoft's topological qubits, indicate that we may be close to overcoming the main technical limitations, particularly decoherence, which has always prevented qubits from maintaining their quantum state long enough for complex calculations. The realization of quantum computers with thousands, even millions of entangled qubits, would give us the most powerful computing system ever built. The implications are as exciting as they are complex to manage [70]. The computational power of quantum computers could be used to help humanity, accelerating scientific research, the development of new materials and drugs, the optimization of complex systems, and even space exploration. At the same time, this technology could become a pervasive tool of control and surveillance, especially considering its implications for cybersecurity. As with any revolutionary technology, the way we model and govern the development of quantum computing will determine whether its benefits outweigh the potential risks. Adequate preparation, both in terms of research and regulation, represents the key to maximizing the positive potential of this extraordinary emerging technology.

Despite all these advances, it is important to note that NASA recognizes that current NISQ (Noisy Intermediate-Scale Quantum) quantum processors are still too small and not robust enough for large-scale applications. However, there are already "physics-inspired classical algorithms" developed by NASA that can be used at the application level today. Quantum technology is rapidly evolving: some use cases, as we have seen, are already operational in specific areas, while others are in advanced stages of experimentation, showing promising results [71].

Access to the cloud represents the present and near future of quantum computing applications, making this technology increasingly accessible [72].

SUMMARY

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[3] Qubit is the abbreviation for quantum bit and represents the fundamental unit of information in quantum computing, analogous to how the bit is the basic unit of classical computing. A classical bit can only take two states: 0 or 1. A qubit, however, thanks to the laws of quantum mechanics, can be in a superposition of states: it can be 0, 1, or both simultaneously. This property is called quantum superposition and allows quantum computers to process much more information than traditional computers, performing complex calculations in much shorter times.

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https://www.its-ictpiemonte.it/news/come-funziona-un-computer-quantistico/

[10] Giancarlo Calzetta, "The revolution will not start from computing" in "ilsole24ore.com" on January 9, 2025.

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[11] Michio Kaku, "Quantum Supremacy. How quantum computers will reveal the mysteries of science and how to face humanity's greatest challenges," ed. Random House USA Inc.

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https://it.linkedin.com/pulse/cosa-cambier\�\�-davvero-con-il-quantum-computing-uese-italia-spa-qxgpf

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https://tech4future.info/quantum-noise-quantum-computing-2024/

[14] In reliability engineering, fault tolerance is the ability of a system not to suffer failures (i.e., service interruptions) even in the presence of faults. Fault tolerance is one of the aspects that constitute reliability.

[15] Yuri Alexeev, Ankit Kulshrestha, Ilya Safro, "Challenges and Opportunities of Scaling Up Quantum Computation and Circuits" in "siam.org" on May 1, 2024.

https://www.siam.org/publications/siam-news/articles/challenges-and-opportunities-of-scaling-up-quantum-computation-and-circuits/

[16] Shor's factorization algorithm is an algorithm devised in 1994 by Peter Williston Shor to solve the problem of factoring integers into prime numbers. On a quantum computer, this algorithm has a computational complexity of BQP (Bounded error Quantum Polynomial time): the prime factors are found with an arbitrarily small margin of error in a "polynomial time" related to the length of the integer to be factored. Shor's algorithm consists of two

steps: a reduction, which can be performed on a classical computer, of the factorization problem to an order calculation problem, and the resolution, via a quantum algorithm, of the order calculation problem.

[17] Federico Mattei (Quantum Business Developer IBM), "CyberSEC2025" in "youtube.com".

https://www.youtube.com/watch?v=NbXng_5C6rc

[18] Gil Kalai's thesis (Hebrew University of Jerusalem) challenges the validity of the "threshold theorem," a pillar of fault-tolerant quantum computation. According to his mathematical analyses, errors in quantum gates are not independent but correlated, making correction codes ineffective. This would imply that any attempt to scale systems would multiply errors rather than correct them; a critique supported by demonstrations on the topological sensitivity of noise. There is also that of physicist Michel Dyakonov, who points out that controlling a system with N qubits requires precisely 2^N parameters - for N=300, a number greater than the photons in the observable universe. This would make the precise control necessary for complex algorithms physically impossible, relegating quantum computers to specialized tools for narrow problems.

[19] Luca De Biase, "The quantum computer is a realistic prospect" in "ilsole24ore.com" on February 11, 2024.

https://lucadebiase.nova100.ilsole24ore.com/2024/02/14/il-computer-quantistico-e-una-prospettiva-realistica/

[20] In 1965, Gordon Moore, head of R&D at Fairchild Semiconductor, hypothesized that the number of transistors in microprocessors would double approximately every 12 months. In 1975, this prediction proved correct, and before the end of the decade, the times extended to two years, a period that remained valid throughout the 1980s.

[21] Luca De Biase and Roberto Sagri, "The revolution of the quantum computer" at the Technology Biennale of the Politecnico di Torino on April 19, 2024.

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[22] Patrizia Licata, "The quantum computer arrives in business. Here's what it is, how it works, and what are the first commercial applications" in "ai4business.it" on November 28, 2024.

https://www.ai4business.it/quantum-computing/computer-quantistico-quantumcomputing/

[23] "The future of quantum computing: research, application, scenarios" In "netgroup.it" on March 15, 2023.

https://www.netgroup.it/il-futuro-del-quantum-computing-la-ricerca-le-applicazioni-gli-scenari/

[24] Marco Brunasso, "Quantum computing in Italy: investments grow, but challenges persist" in "techbusiness.it" on March 31, 2025.

https://techbusiness.it/quantum-computing-italia-investimenti-2025-sfidetecnologiche/

[25] "Quantum computing: in the Bel Paese investments grow" in "lineaedp.it" on March 28, 2025.

https://www.lineaedp.it/report/quantum-computing-nel-bel-paese-crescono-gliinvestimenti/

[26] "From supercomputing to smart cities, Italy's role in quantum computing. The analysis of the ICSC Observatory" in "Industriaitaliana.it" on March 6, 2025.

https://www.industriaitaliana.it/supercalcolo-smart-cities-italia-quantum-computing-osservatorio-icsc/

[27] Molecular docking is a computational technique that allows the study of the interaction between two molecules. It is used, in particular, to study the interaction of proteins with other molecules of biomedical interest, such as nucleic acids, drugs, and other proteins. Docking literally means docking, mooring; this term attributed to molecules indicates how they hook onto each other.

[28] ICSC Observatory, "From supercomputing to smart cities, Italy's role in quantum computing" in "industriaitaliana.it" on May 3, 2025.

https://www.industriaitaliana.it/supercalcolo-smart-cities-italia-quantum-computing-osservatorio-icsc/

[29] Stefano Casini, "Quantum computing as a key factor for the digital transformation of the manufacturing sector" in "innovationpost.it" on May 5, 2023.

https://www.innovationpost.it/attualita/il-quantum-computing-fattore-chiave-per-la-trasformazione-digitale-del-settore-manifatturiero/

[30] Massimo Iengo and Emiliano Luzietti, "PwC Italy and Quantum Computing: innovation in the energy & utilities sector" in "pwc.it" on March 18, 2025.

https://blog.pwc.it/pwc-italia-quantum-computing/

[31] IT infrastructure is everything needed by the user to create and run software applications in an organization. It includes hardware, network components, operating system, data storage, and various software used by an organization to provide IT services and to run internal software solutions.

[32] "In the Bel Paese investments grow" in "lineaedp.it" on March 28, 2025.

https://www.lineaedp.it/report/quantum-computing-nel-bel-paese-crescono-gliinvestimenti/

[33] Marco Brunasso, "Investments grow but challenges persist" in "techbusiness.it" on March 31, 2025.

https://techbusiness.it/quantum-computing-italia-investimenti-2025-sfidetecnologiche/

[34] "Drug discovery with AI" in "tecnomedicina.it" on September 10, 2024.

https://www.tecnomedicina.it/il-quantum-computing-per-la-scoperta-di-nuovi-farmaci/

[35] Post-quantum cryptography (PQC) is a set of cryptographic techniques designed to be secure even against attacks from quantum computers, which could break traditional algorithms. Advanced sensing, on the other hand, refers to sophisticated detection technologies and devices that allow data acquisition with greater precision, speed, and capacity compared to traditional sensors. These sensors are often integrated into complex systems for applications in various sectors such as industry, medicine, automation, the Internet of Things (IoT), and robotics.

[36] Paolo Savona and Fabio Vanorio, "The superpower of the future will have to dominate the quantum. Here's why" in "startmag.it" on June 4, 2023.

https://www.startmag.it/innovazione/la-superpotenza-del-futuro-dovra-dominare-la-quantistica-ecco-perche/

[37] "A guide to quantum technologies in the world" in "bitmat.it" on July 18, 2024.

https://www.bitmat.it/news/una-guida-sulle-tecnologie-quantistiche-nel-mondo/

[38] Euro QCS Italy is an Italian project part of the European initiative EuroQCS (European Quantum Computing & Simulation Infrastructure), which aims to develop and host a quantum computer in Italy. QUID is also part of the European initiative EuroQCI (European Quantum Communication Infrastructure), but concerns the development of a secure and advanced quantum communication network in Italy.

[39] IQM Radiance is a full-stack superconducting quantum computer designed for integration into high-performance computing centers (HPC). Available with configurations of 20, 54, or 150 qubits, it is designed to tackle complex and data-intensive problems, offering high fidelity (99.9%) and low latency thanks to on-premise installation, i.e., directly at the user's site.

[40] "In Italy a new quantum computer worth 13 million euros" in "esteri.it" on March 28, 2025.

https://ambsantodomingo.esteri.it/it/news/dall_ambasciata/2025/03/in-italia-un-nuovo-calcolatore-quantistico-da-13-milioni-di-euro/

[41] Alberto Cantoni, "Where are we with Quantum Computing in Europe" in "linkiesta.it" on August 30, 2023.

https://www.linkiesta.it/2023/08/quantum-computing-europa/

[42] "Deciphering the future: an introduction to quantum computing" in "innova.ms".

https://innova.ms/decifrare-il-futuro-un-introduzione-al-quantum-computing/

[43] "The impact of Quantum Computing on society" in "digicert.it"

https://www.digicert.com/it/blog/the-impact-of-quantum-computing-on-society

[44] "What is quantum computing and what should companies know about this technology" in "sectigo.com" on August 8, 2024.

https://www.sectigo.com/it/risorse/guida-informatica-quantistica-aziende

[45] "Exploring the fun and imaginative uses of Quantum Computing: Insights from a Recent Survey" in "quera.com" on July 19, 2024.

https://www.quera.com/blog-posts/exploring-the-fun-and-imaginative-uses-of-quantum-computing-insights-from-a-recent-survey

[46] Donatella Maisto, "Quantum technology, funding and opportunities awaiting 2025" in "quifinanza.it" on December 6, 2024.

https://quifinanza.it/innovazione/quantum-finanziamenti-opportunita/868735/

[47] "Important discovery by Microsoft for the realization of topological qubits" in "quantumcomputinglab.it".

https://www.quantumcomputinglab.cineca.it/2022/03/24/importante-scoperta-di-microsoft-per-la-realizzazione-di-qubit-topologici/

[48] Symmetric algorithms are encryption methods that use a single secret key shared for both encrypting (encrypting) and decrypting (decrypting) data. This means that the sender and recipient must possess the same key, which must remain confidential to ensure the security of the communication.

[49] The RSA protocol is an asymmetric cryptography system, devised in 1977 by Ron Rivest, Adi Shamir, and Leonard Adleman, from which it takes its name. It works by using a pair of keys: a public key, accessible to anyone for encrypting messages, and a private key, secret, used for decrypting them. In summary, RSA is a fundamental algorithm for digital security, based on public and private keys, ensuring the privacy and authenticity of transmitted information.

[50] Andrea Viliotti, "Why quantum computers put data security at risk" in "ai4business.it" on November 6, 2023.

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[51] Giorgio Sbaraglia, "Do quantum computers threaten cryptographic algorithms? The risks and what is being done to mitigate them" in "cybersecurity360.it" on November 15, 2023.

https://www.cybersecurity360.it/nuove-minacce/i-computer-quantistici-minacciano-gli-algoritmi-crittografici-i-rischi-e-cosa-si-sta-facendo-per-mitigarli/

[52] "The Quantum Insider Projects $1 Trillion in Economic Impact From Quantum Computing by 2035" in "thequantuminsider.com".

https://thequantuminsider.com/2024/09/13/the-quantum-insider-projects-1-trillion-in-economic-impact-from-quantum-computing-by2035/

[53] Marina Natalucci, "Quantum Computing & Communication" in "osservatori.net".

https://www.osservatori.net/quantum-computing-communication/

[54] Federico Mattei (Quantum Business Developer IBM), "CyberSEC2025" in "youtube.com".

https://www.youtube.com/watch?v=9IC9PpGH7fI

[55] Noise reduction in quantum computing refers to the techniques and methods used to minimize or correct quantum noise, i.e., the disturbances and interferences that alter the state and results of a quantum system, such as a quantum computer or a quantum communication device. In detail, quantum noise is caused by factors such as external magnetic fields, electromagnetic interferences (WiFi, cell phones), and the interaction between qubits themselves, which can lead to errors in the manipulation of quantum information and the loss of coherence (quantum decoherence). This noise makes the results of quantum calculations uncertain and limits the duration and reliability of quantum states.

[56] Qiskit is an open-source software development kit (SDK), created by IBM, that allows programming, simulating, and executing quantum algorithms on real quantum computers or classical simulators.

[57] Cristiano Matricardi, "QU-BIT. Episode 8. The professions of tomorrow" in "nature.com" on May 6, 2024.

https://www.nature.com/articles/d43978-024-00078-3

[58] A significant example is represented by the Master in Quantum Communication and Computing launched by the Politecnico di Torino, the first in the country, which began in October 2023. This initiative, carried out in collaboration with the National Institute of Metrological Research-INRiM and Links Foundation, aims to create specialized figures that meet the needs of the labor market in this sector.

[59] The Politecnico di Torino has launched the first Master in "Quantum Communication and Computing." A training path that began in 2023 in collaboration with the National Institute of Metrological Research INRiM and Link Foundation aims to create specialized figures that meet the needs of the labor market.

[60] The Quantum Physicist possesses an in-depth understanding of quantum mechanics and contributes to the fundamental research that drives technological development. Quantum physicists are essential in solving problems related to quantum coherence and noise reduction in quantum systems; Quantum Engineer. The Quantum Engineer primarily deals with the development of the hardware architectures of quantum computers and quantum sensors, such as the design and construction of quantum hardware, the coding of quantum software, and the conduction of experiments to test and refine quantum systems. Quantum Computer Scientists have an experimental approach and focus on solving complex problems using quantum theory. Their responsibilities include developing specific quantum algorithms for complex computational problems and creating quantum simulations to verify theories. Quantum Software Specialists deal with the optimization of quantum circuits to improve performance and reduce computational errors, as well as developing and implementing error correction and mitigation techniques for quantum calculations. The Quantum Developer focuses more on technical aspects and deals with developing quantum software based on existing projects.

[61] "New drugs thanks to AI: here are the expected breakthroughs in 2025" in "agendadigitale.eu".

https://www.agendadigitale.eu/sanita/ai-e-genomica-la-nuova-frontiera-della-scoperta-di-farmaci/

[62] Drag and drop is a computer technique that consists of a sequence of three actions: clicking on a virtual object (for example, an icon or a window), dragging it with the mouse or finger to another position, and releasing it in that new position. Drag and drop is considered a form of direct manipulation, where the user interacts with objects on the screen in an intuitive way, similar to the physical world, by "grabbing" an object and "moving" it directly.

[63] Marina Natalucci, "Quantum Computing & Communication" in "osservatori.net".

[64] Manuele Bassanini, "A revolutionary technology that takes us into the future" in "itimpresa.it" on September 2, 2021.

https://www.it-impresa.it/blog/qubit/

[65] Nielsen, Michael A. and Chuang, Isaac L. (2010), "Quantum Computing and Quantum Information" (2nd ed.) ed. Cambridge University Press.

[66] John Preskill, "Quantum Computing in the NISQ era and beyond" in "quantumjournal.org" on January 2, 2018.

https://quantum-journal.org/papers/q-2018-08-06-79/

[67] Jonathan P. Dowling and Gerard J. Milbur, "Quantum technology: the second quantum revolution" in "royalsocietypublishing.org" on December 3, 2012.

https://royalsocietypublishing.org/doi/10.1098/rsta.2003.1227

[68] "Transpilation" is the procedure that takes code written in one language and translates it into another high-level language, maintaining the same logic and structure, unlike traditional compilers that translate from a high-level language to a low-level one.

[69] "Quantum Computing in Action: QuEra Case Study" in "quera.com" on April 22, 2025.

https://www.quera.com/blog-posts/quantum-computing-in-action-pawsey-quera-case-study

[70] "The promise of topological qubits: a deep dive" in "quantumai.co" on December 27, 2024.

https://quantumai.co/it/la-promessa-dei-qubit-topologici-unimmersione-profonda/

[71] "The future of Quantum Computing: research, innovation, scenarios" in "netgroup.it" on March 15, 2023.

https://www.netgroup.it/il-futuro-del-quantum-computing-la-ricerca-le-applicazioni-gli-scenari/

[72] Francesco La Trofa, "Discovering the potential of Quantum Computing" in "tech4future.info" on February 24, 2022.

https://tech4future.info/quantum-computing-use-cases-2022/

Massimo Tamiatti

I have always been involved in the study and dissemination of topics related to new technologies, new jobs, and new skills. I do this in a completely new and different way compared to traditional research approaches because, in addition to consulting traditional sources, I consult sources from major strategic consulting firms, which do not have a static but dynamic vision of reality, as they focus on the future. I systematically use the web to search for the most up-to-date content, perhaps through webinars with privileged witnesses on the subject of the investigation or through some important influencer specialized in the topic being addressed. Obviously, today, I use Generative Artificial Intelligence tools. I do not neglect the present; I try to interpret the signals that we have before our eyes, which we are often used to looking at and not seeing, and which suggest what could happen. I do not neglect the past, that is, history, but in reality, many disciplines are mixed: economics, statistics, sociology, psychology, anthropology, and above all, I use imagination anchored to the facts that happen every day in the world. I consider numbers very important, but they are not everything; at the center, there must always be a particular attention to the privileged witnesses of the things that happen and their personal stories. Frontiere does not have the gift of foresight, but our team can make hypotheses, and among these hypotheses, I have realized that it is very likely to encounter the future. Spreading the culture of anticipation helps people understand what is happening in the world, especially in the world of work, helps them prepare, elaborating strategies, and organizing themselves to make very important conscious and correct choices for the effect they will have on their lives.

Institutional Profile

I was Chief Research Officer of the Agenzia Piemonte Lavoro, where I coordinated groups of researchers in the field of labor and vocational training policies until June 30, 2023. Since July 1, I have become part of the staff of the "Laboratorio Riccardo Revelli" as an honorary member. I am an expert in public employment services. Currently, I am a member of the group that coordinated the organization of the "Settimana del lavoro 2024" and related events on behalf of the Istituto per la memoria e cultura del lavoro, dell'impresa e dei diritti sociali (ISMEL), of which I am a member of the scientific committee. I am a member of the scientific committee of Polis policy, Accademia di alta formazione. I am the founder and director of the online scientific dissemination site **http://www.frontieretecnologialavoro.com** since 2022 and a member of the Associazione dei Futuristi italiani di Roberto Poli. I am an expert in the use of forecasting techniques applied to local labor markets, in collaboration with the start-up Skopìa, specialized in future studies and anticipation, aimed at helping organizations develop anticipatory strategies to support complex decisions in areas of strong uncertainty. I have a degree in letters and philosophy, with a thesis in contemporary history and one in political science, both obtained from the University of Turin, and I am the author of numerous publications related to the labor market, and in particular to the new scenarios of the labor market, new professions, and new skills.

The following collaborated with me on this project: Gabriele Lamberti, Benjamin Dafku, Ivan and Federico Giacobino.