The Impact of Quantum Computing on Businesses

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Abstract. Despite the fact that data science continues in a constant evolution, there are still many problems that are still impossible to solve due to processing issues, either due to the exorbitant amount of data collected, or related to the different types of data to be processed. Quantum computing in the last decade has experienced a significant boom which has allowed researchers to pose problems that until now were impossible to solve in the classical paradigm. Quantum computing promises gains by solving how we solve these challenging computational problems. Currently, creating added value and achieving new experiences for the consumer, enhanced with it combination with artificial intelligence and machine learning, being a determining factor to promote business competitive advantage. This article aims to assess the impact of quantum computing on businesses competitive advantage, through a qualitative bibliographic analysis. In this context, an extensive research was carried out in this area on Web of Science and Scopus for the period 2016–2021. The survey covers 162 papers selected for this study, 92 from Scopus and 70 from Web of Science.

Keywords: Quantum artificial intelligence applications · Quantum machine learning · Quantum computing · Business competitive advantage

1 Introduction

With the acceleration of the digital transformation caused by the pandemic, technology has had a major impact on the world economy through the new opportunities that have arisen for companies in terms of implementing various digital solutions that have allowed them to improve, expand and facilitate their processes.

Quantum computing (QC) in the last decade has experienced a significant boom which has allowed researchers to pose problems that until today were impossible to solve in the classical paradigm [1].

Computers automating virtually all processes and systems that facilitate decision-making in any company are no longer as far away as they seemed. Quantum computing is leaving the laboratories of large technology companies to enter the daily lives of companies of all sizes and in any market segment.

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There are several works that today focus on studying the potential applications of QC, in different sectors. In organizations, there are many challenging issues, and QC promises gains by solving how we solve these challenging computational problems.

Currently, creating added value and achieving new experiences for the consumer, enhanced with artificial intelligence, has become a determining factor that can promote business competitive advantage [2].

This research was supported by a bibliographical review and analysis in the areas of QC, artificial intelligence (AI), and machine learning (ML), with the aim of evaluating the impact of QC on business. In addition to understanding the impact at business competitive advantage by providing support regarding decision making.

For the survey, the chosen international databases responsible for scientific publications of an interdisciplinary nature, was Web of Science (WoS) and the Scopus. The terms used for the search was "Quantum Computing". Having presented a total of 33,368 documents, distributed between 2016 and 2021 (Fig. 1), being 34% Scopus and 66% Web of Science.

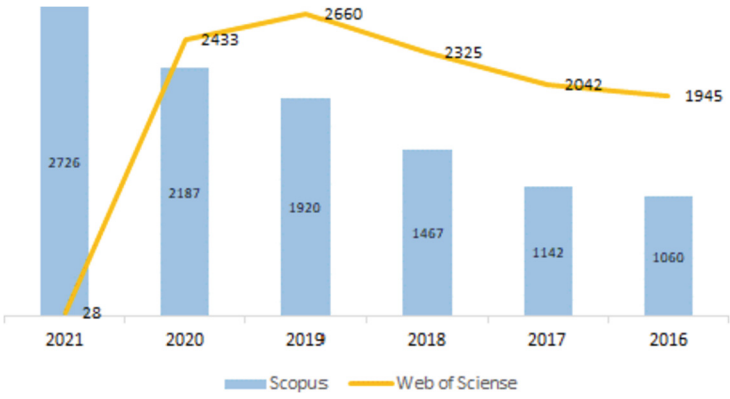

Fig. 1. Chronology of research terms between the years 2016–2021 at WoS and Scopus.

The research area with the most publications, in the case of WoS is Physics and Astronomy Astrophysics, totaling 63%, followed by Chemistry with 21%. In the case of Scopus is Computer Science with 22% of publications, followed by Physics and Astronomy Astrophysics, with 21%. Although there is some balance between the areas with more publications between the two indexing platforms, it is possible verify at Fig. 2, that 3 these research areas stand out due to their asymmetry: Physics and Astronomy Astrophysics; Chemistry; and Mathematics.

Although Scopus and WoS publications have the same countries in the top 9, in terms of number of publications they only present the two countries with the highest number of publications in the same order, United States and China (Fig. 3), in the case of WoS the 3rd was changed with India.

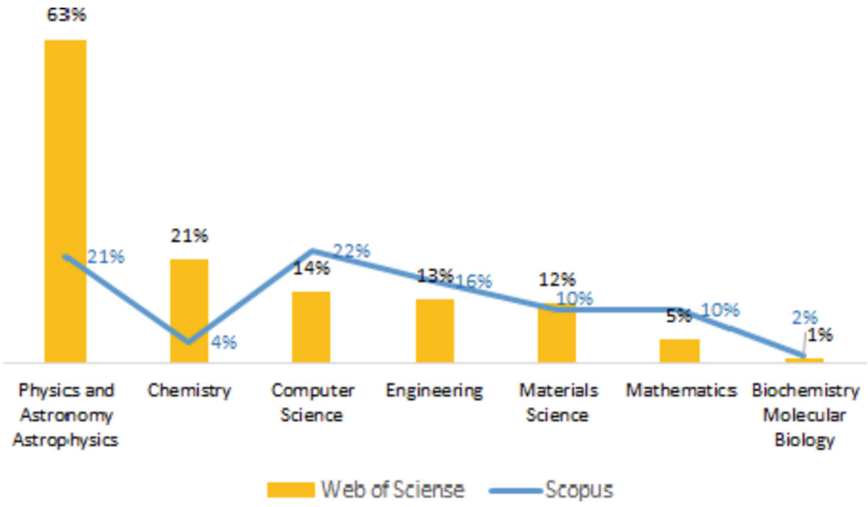

Fig. 2. Distribution by research areas between the years 2016–2021 at WoS and Scopus.

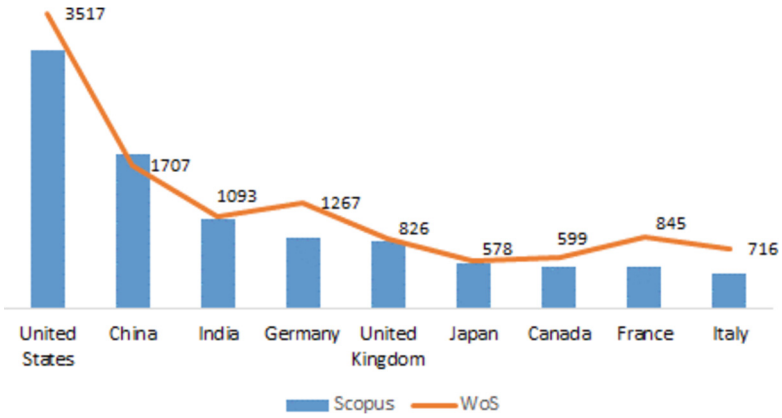

Fig. 3. Distribution by country between the years 2016–2021 at WoS and Scopus.

2 Quantum Computing

In the 1980s, two important fields of research focused on the domain of quantum mechanics emerged: quantum information and quantum computing. Both with the aim of applying the quantum systems in a computational apparatus, for the manipulation of information [3].

The quantum computer is a programmable device capable of performing calculations and algorithms by manipulating and reading information stored in quantum systems, such as atoms, molecules, protons, electrons and photons. In this type of computer, quantum bits are used, which, due to their nature, make this type of computer capable

of performing tasks that would take thousands, or even millions of years to be done by electronic computers [4].

A quantum computer is a collection of n qubits on which it is possible to prepare in a state known as $| 0 >$ which can be measured in the basis ($|0 >, |1 >$). This foundation of computing is based on the principles of superposition of matter and quantum entanglement to develop a different computation [5].

Traditional computers work on binary numbers and allow us to input information to obtain results. Which means, when performing calculations, we need to establish a series of rules that determine exactly what kinds of answers we are able to get. The whole process involves adding, subtracting, multiplying and dividing data to obtain valid variables.

The difference between electronic and quantum computers is that, due to the probabilistic nature of quantum physics, before be read the quantum bit, its state can be not only 0 or 1, but also the intersection between these states. It is as if quantum computers accepted answers like yes, no and both simultaneously. If you want to better understand the probabilities of the quantum world [1, 6].

The quantum computers being developed today use light particles, trapped ions, superconducting qubits and observing nitrogen in imperfect diamonds [7].

QC will have the ability to address and help solve a varied range of problems, from process optimization to simulation and machine learning [8, 9]. Therefore, some potential applications can already be seen on the horizon of quantum computing in the industry. Being related to the resolution of mathematical problems; the use of quantum artificial intelligence; training deep learning and cybersecurity models; the development of batteries with greater capacity and charging speed.

The potential of QC is so great, and technology advances so fast, that companies need to have a basic understanding of how the technology works, what kinds of problems it can solve, and how they can take advantage of it. There are several sectors already involved: logistics, financial, chemical, energy, pharmaceutical, cybersecurity, and industrial; where quantum computing has great potential [10–15].

The high processing capacity of these computers will be able to trace complex paths and make projections of each possible decision to be taken by companies, such as investment management, risk measurement in different scenarios and research, leaving companies even more capable and planned for any event.

Developing applications with this new technology can make cloud computing services much more agile and powerful. In addition, quantum computing research talks about hardware that could be offered in the future as a cloud service [16].

Given this, giant technology companies are investing heavily in technology to get ahead and have computers capable of solving unimaginable problems. Everything is still recent and companies are not sure how this quantum future will work, but that hasn't stopped them all from starting some wild project.

Organizations with precarious computing resources in the area of optimization or data security must begin to understand how this technology could solve their problems, since through quantum formulations it will be possible to retain any and all knowledge in an optimized way and still receive suggestions with statistical data calculated according to the organizations objective.

There are three main types of quantum computing: Quantum Annealing (QA); Quantum Simulation (QS); and Universal Quantum (UQ). Each has different processing power and time, as well as the time it takes to be commercially viable [17, 18].

QA it's the least powerful (like traditional computers) and most restrictive type; it's easy to build; and a good option to optimizing problems.

In the case of QS, it is capable of simulating complex quantum interactions that are intractable for any known conventional machine; with an average difficulty in build-up; containing between 50 and 100 qubits. It can be apply at quantum chemistry; material science; optimization problems; and sampling quantum dynamics.

The third type, UQ, it's the most powerful, but posing a series of difficult technical challenges; it's the hardest to build; and compromise more than 1000,000 physical qubits [19]. This type has a wide application areas: machine learning; secure computing; cryptography; quantum chemistry; material science; optimization problems; and sampling quantum dynamics.

3 Quantum Machine Learning

The goal of Machine Learning (ML) is to teach the machine how to perform a specific task, without providing explicit instructions. It is divided into three main families: supervised learning; unsupervised learning; and reinforced learning.

Supervised learning is without doubt the most famous and developed aspect of automatic learning, both in academic and industrial research. It is also the case of quantum automatic learning, and many works have attempted to adapt classical supervised algorithms to the quantum configuration [20, 21].

The neural networks are one of the most commonly used supervised algorithms, due to their ability to classify and make accurate predictions. In the literature, several models of quantum and quantum neural networks have been proposed, with different ways of encoding the data [22].

QC was also introduced to various unsupervised learning algorithms, providing new quantum-enhanced machine learning algorithms.

Quantum principal component analysis (QPCA), was proposed by Llyod et al. [23], and exploits the spectral decomposition of the Variational Quantum Eigensolver. Many works have been derived from it, providing improvements in the performance or precision of QPCA [24].

Recently, QPCA was used in finance to simulate the Heath-Jarrow-Morton model for the pricing of interest rate financial derivatives [25].

Reinforced learning has received less interest than the other two machine learning approaches, but interesting proposals were made nonetheless. Many jobs were derived from it, providing improvements in performance with the precision of QPCA. Recently, QPCA has been used in finance to simulate the Heath-Jarrow-Morton model for fixing the prices of financial derivatives of interest types [23–25].

Most of the works are based on the agent model, where an agent interacts with its environment and selects the best actions to maximize a reward function [26]. In others works experimental experiments have been proposed, using superconducting circuits [27], quantum optical neural networks [28], and others.

In the last few years, with the development of Machine Learning techniques, many problems have been addressed using these algorithms with the help of a large amount of compiled data. However, considering the most difficult problems that our society faces, the algorithms and real machine learning approaches show some limitations in terms of size and the amount of data that can be processed, but also from the point of view of efficiency and the income.

Quantum Machine Learning (QML), have three different approaches. The first is to apply classical machine learning to solve problems in quantum physics or quantum information. The second is to use quantum computations to speed up classical machine learning techniques, sometimes leading to hybrid algorithms. This is also known as quantum enhanced machine learning. The last one is to use pure quantum models or adaptations of learning algorithms to exploit the full potential of quantum mechanics and quantum information processing [21, 29].

QML has the potential, to exploit the advantages of the quantum computing and the quantum information process, to help the machines to learn faster and to tackle the most difficult tasks.

4 Quantum Artificial Intelligence Applications

The quantum artificial intelligence makes reference to the use of quantum computers for the processes of machine learning algorithms. The objective is to take advantage of the superiority of the processing of the quantum computing to obtain unattainable results with classic computer technologies. There are several possible applications like: data sets integration; process large data series; agile resolution of complex problems; and increased business insight and improved business models.

To handle and integrate multiple data sets from different sources, quantum computers also offer great help, speeding up processes and facilitating analysis.

The ability to handle volumes of such complex information makes quantum computing the ideal choice for solving business problems in a wide range of fields.

We produce 2.5 exabytes of data every day. An amount equivalent tof 5 million laptops. Every minute of every day, the 3.2 billion Internet users in the world continue to feed the databases adding 9,722 pins on Pinterest, 347,222 tweets, 4.2 million “likes” on Facebook, in addition to an infinity of other data in other formats, such as photos, videos, documents, information to create accounts, and others [30].

Quantum computers are designed to handle large volumes of data, as well as discover patterns and detect anomalies extremely quickly. Successive iterations of quantum computer designs and improvements in quantum error-correcting code are allowing developers to harness more and more of the potential of quantum bits. At the same time, they make it possible to optimize said potential to solve all kinds of problems that companies face when making decisions.

Quantum computers are capable of solving calculations in a matter of seconds that a current computer would take years. With quantum computing, developers can simultaneously perform multiple calculations on multiple input data. Quantum computers are essential for processing the endless stream of data that companies generate on a daily basis. In terms of calculation speed, these computers are capable of quickly solving

extremely complex problems [31]. This ability is what is known as quantum supremacy. Thus, a quantum computer can carry out calculations in 200 s that would take a traditional computer 10,000 years. The key is to translate the real-world problems that companies face into quantum language [32].

With the increasing amount of data generated in industries such as pharmaceuticals, financials and life sciences, companies are losing their ties to classical computing rope. In order to have a better data framework, these companies now need complex models with enough processing power to model the most complex situations. And that is where quantum computers are called to play a very important role. The creation of better models with quantum technology will speed up many processes. Thus, in the health sector, it will make it possible to greatly shorten the development cycles of disease treatments, as in the case of COVID-19, shortening the cycle of research, testing, monitoring and treatment of the virus. On the other hand, in the banking sector, it will help reduce cases of financial implosion, or improve the logistics chain of the manufacturing sector.

5 Impact of QC on Businesses

Quantum computers will be disruptive for all industries, this dysfunction could influence / benefit companies at various levels.

One of the main differentiators that can be expected with quantum computing is an increase in online security, whose only negative point is the obsolescence of the encryption systems we use today [33]. QC will allow for a more organized distribution of information and the creation of extremely secure communication methods.

Although the impact of AI already makes a difference in the daily lives of companies, with quantum computing this impact will be much greater, since these systems are able to absorb and analyze more information simultaneously, and will be better to provide AI with the information and feedback they need to perform optimally [34]. This will reduce the systems learning curve, and they will be able to correct their errors quickly and self-sufficiently. The result is a technology that is more intuitive and advances faster.

The market value of quantum computing is expected to be around $2.2 billion in 2026. By then, it is estimated that there will be a total of around 180 installed quantum computers (45 of them produced in the same year). These figures include both equipment installed in the quantum computing companies themselves that offer quantum services, as well as local machines in customer premises [35].

For businesses to survive and acquire or maintain a competitive advantage, they need to be able to determine a number of likely outcomes from existing information (internal and external), that is, predictability, which increases with quantum superposition.

As quantum computers are able to analyze multiple data matrices at the same time and without losing efficiency, they will allow for much greater predictability, improving results.

Currently, there is still no passive production or sale of viable quantum computers. However, this is a technology that will be part of our future and that organizations should be aware of, as it represents a series of possibilities that will help deliver a better level of service and more efficiency to their consumers.

Microsoft developed Microsoft Quantun, an open Cloud Quantum Computing and Optimization ecosystem that features partner solutions, learning resources for developers, researchers, and students. It is from this ecosystem that Microsoft believes it is possible to accelerate the development and growth of Quantum Computing, since it has prebuilt solutions that guarantee rapid development. The solutions are customized and prepared for both integration and data submission. Thus, the optimized development process with Azure Quantum guarantees cost savings in the medium and long term [36, 37].

As a complement, Microsoft launched a Quantum Development Kit, which allows developers to build algorithms using the Quantum language Q#, created by the company. With applications being able to be tested in local simulators, such as notebooks or desktops, with up to 30 logical qubits of power for quantum circuits, or even via Microsoft Azure, with a power close to 40 qubits [38].

Quantum computing is reaching a commercialization phase that could change our world. Early adopters of quantum's unique ability to solve certain types of problems can make breakthroughs that enable new business models.

Visionary organizations are already lining up with the emerging quantum computing ecosystem to become "quantum-ready" [39]. These pioneering companies are exploring use cases and associated algorithms that address complex business problems. This report discusses the paradigm shift that quantum computing represents for business, explains why your company may need to act now, and provides five recommendations for leveraging your organization through the business advantage that quantum provides. Quantum computing is reaching a commercialization phase that could change our world. Early adopters of quantum's unique ability to solve certain types of problems can make breakthroughs that enable new business models [40].

Quantum systems can trigger the discovery of new materials and new drugs, and allows that logistics and supply chains to be extremely efficient, as well as helping to find new ways to model financial data and isolate key risk factors to make better investments. Quantum computing can contribute to more dynamic artificial intelligences capable of dealing with a greater number of problems [8, 11, 13, 18, 29].

The encryption, one of the main data security mechanisms, will need to be revised, as the speed of calculations of a quantum computer will be able to unravel current codes in seconds. But on the other hand, quantum cryptography would be totally secure and virtually unbreakable.

Digital transformation in companies grows at exponential speed and the arrival of this technology will change the shape of many business models, opening doors for innovation. Company's IT area needs to be up to date and prepared for all the changes that are to come.

It is evident that we have to wait, but we have one certainty: quantum computing brings a vast world of possibilities to the corporate universe. Current industry trends related to quantum computing are (Fig. 4): chemicals & pharma; computer science; cybersecurity; energy & utilities; financial services; logistics & transport; media & marketing; military; and telecommunications.



Fig. 4. Quantum computing current industry trends.

6 Conclusions

Quantum computing it's a real technology that will transform our future and that of virtually every industry. It is a disruptive technology that will solve several problems in today's business ecosystem.

Quantum computers are very different from the computers we use on a daily basis because the information processing is done following the rules of Quantum Physics. In a traditional computer, information is processed in 0 and 1 (bits), while in a quantum computer, information can be 0 and 1 at the same time (quantum bits or qubits), which exponentially increases the information processing capacity.

Quantum computers solve problems that classical computers are no longer able to answer. It is this additional information processing power that will dictate new opportunities in the business world.

There is a lot of promise around quantum computing, although there is still no transformative solution based on it. However, today, a lot is already known, due to the various tests and developments carried out with the technology in recent years.

The potential is so great, and technology advances so fast, that every leader needs to have a basic understanding of how technology works, the types of problems it can solve, and how to prepare to harness its potential.

In the near future, quantum computing will transform almost every aspect of technology, taking a broad approach to a range of problems, from process optimization to simulation and machine learning.

Access to cloud-hosted quantum services (Quantum Computing as a Service (QCaaS)) will be the main source of revenue for quantum computing companies, accounting for 75 percent of all quantum computing revenue by 2026. In the long term the acquisition of quantum equipment becomes a more frequent option, at present, the

interest of potential end users is focused more on access to quantum computing capabilities through the cloud, avoiding making technologically risky and expensive investments in quantum computing equipment [41].

Quantum computing is a bet for the future of business and should have an impact on our routine in the next 5 to 10 years. To take the technology from the labs to the day to day of companies, big corporations, such as IBM, Google and Microsoft, and startups are investing their efforts in improving this solution.

In the next 5 years we will see a boom in the number of quantum software applications, quantum development tools, and quantum engineers and experts, as infrastructures expand, and this will allow more organizations to harness the power of two transformational technologies of quantum computing and AI, so many universities will begin to incorporate quantum computing subjects as core subjects in their curricula.

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