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Quantum Computing and the Business Transformation Journey

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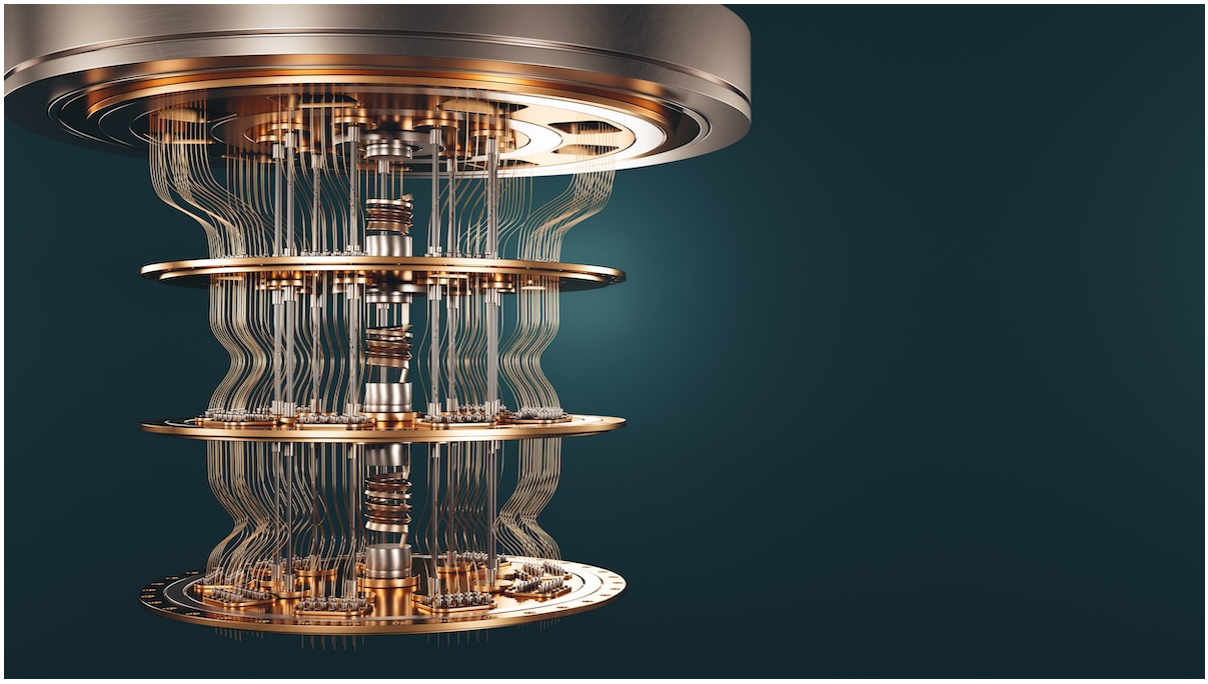

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Quantum Computing impacts business transformation in firms and requires a new mindset for operational excellence.

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1. Introduction

The utilization of quantum computing in organizations has risen in recent years and has led to remarkable changes in business operations around the world. A Fortune Business Insights report indicated that the quantum computing market was valued at $717 Million in 2022 and is expected to reach $6,528 Million in 2030.[1]

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Essentially, a quantum computer resembles a classical computer, however it replaces the binary bit system (0 and 1s) with quantum bits, which are commonly called *qubits*. Unlike binary bits, *qubits* can be both 0 and 1 at once, exponentially increasing the computational power with each new qubit added to the machine.[2]

The dramatic increase in computational power promised by quantum computing is drawing the interest of governments and corporations because it disrupts fields like cryptosecurity, national defense systems, machine learning and AI.

Full-scale quantum computers will ultimately revolutionize decarbonization and the transition to renewables, and quantum-inspired computing, software and algorithms presently offer commercial tools supporting sustainability objectives. [3, 4] For example, quantum-inspired tensor networks increase the computational efficiency of energy-intensive training of machine learning models, without reducing accuracy.

Quantum-inspired algorithms consume less energy than traditional algorithms. Chat-GPT (GPT-3) is estimated to have consumed 1287 MWH of energy and emitted 552 tons of CO2 in the training of the model.[5] If the same training was done using methods from tensor

networks, the energy cost could be reduced to 437 MWH, a reduction of 66%.[6] Only 187 tons of CO2 would be emitted, saving 365 tons of CO2 per training.[7]

Tensor networks are driving efficiencies in the resolution of highly complex equations and processes that hinder sustainability. This technology enables advances, such as the design of new materials for batteries and solar cells, improved modelling of reaction pathways for nitrogen fixation and hydrogen catalysis, and the forecasting of green energy production.

Apart from technological enhancements in products, advancements in quantum technology have contributed to significant business transformation in organizations.

In this article, authors blend their expertise in academia and industry to provide a roadmap to companies considering a journey into the quantum realm.

2. Drivers of the Quantum Movement

Quantum computing gradually evolved from theoretical possibility to commercial reality. Working quantum computers are now available in many countries. Dozens of quantum programming languages and simulators, and quantum computers are used by companies and end users through cloud services provided by companies like IBM, Amazon, Google, Microsoft and D-Wave.

Quantum as a service has grown in usage. Small firms are providing quantum services to companies looking to integrate quantum computing in their core business. Software-focused firms like 1Qbit, ARQIT, SandboxAQ and Multiverse Computing provide software, training, and services related to quantum.

The quantum industry consists of an ecosystem comprised of corporations, academic and public institutions.Public investment worldwide across a range of quantum technologies totaled $30B in the last decade. This investment is mostly aimed at defense and national security solutions in countries like China, Japan, India, US, UK, Germany and Canada.[8]

Private investment is also growing rapidly with $5B global investment and an accelerating shift from venture capital to IPOs and SPACs (special purpose acquisition companies), signaling that the sector is maturing.[9]

The supply chain of the industry is diverse and comprise an estimated one thousand companies.[10]These companies are classified into five distinctive groups:

Component manufacturers. About 40 component suppliers such as Oxford Instruments and Bluefors produce materials, devices and processes used in quantum hardware, such as refrigeration, etching, measurement, wiring, controllers, and software.

Hardware manufacturers. About 50 quantum hardware manufacturers develop two main types of quantum processors called quantum analog machines (including annealing systems) and universal quantum computers built to be versatile and scalable. IBM and Google are dominant players in this space.

Systems software. This sector comprises approximately 40 dominant companies. Leading systems software suppliers and their primary platforms include Zapata's Orquestra, a hardware-agnostic software platform that helps enterprises enhance computationally intense solutions to models like generative AI and Monte Carlo simulations.

Application software. Approximately 70 companies such as Multiverse Computing and ProteinQure offer software as a service to resolve commercial problems through enhancement in R&D and materials design.

Services. About 30 companies such as Zapata offer professional services in the quantum industry and partnered with quantum service providers to explore applications for quantum computing. Deutsche Bahn partnered with Cambridge Computing to optimize train scheduling and increase network capacity.

With industry innovations brought about by quantum computing, organizations are transformed through technological upliftment, operational efficiency, speed in product development, employee productivity improvement, and enhanced service delivery among others.

It is apparent that the quantum computing industry and its practice is moving forward in several directions, and typically accompanying growth are unprecedented challenges.

3. Roadblocks to Business Transformation

The authors identify seven obstacles organizations need to navigate as business transformations unfold across different sectors.

Uncertainty of direction. There is fierce competition over which technology or combination of technologies will prevail in the race to full-fledged quantum advantage. Currently, the competition pitches analog against gate model platforms, each attempting to become the computing gold standard for certain tasks. It is also uncertain which qubit technology (superconducting, ionic, semiconducting) will prevail, each having their strong and weak points. Business organizations need to weigh upon the most optimal model for their firm.

Resource sustainability. Further public and private investment are needed to develop scalable, fully fault-tolerant quantum hardware with enough qubits to completely disrupt commercial applications and processes.[11] Technical issues like 'decoherence' and 'limits on entangled qubits' will require further 5 to 10 years of sustained investment. Continuity of investment is an important issue to consider.

Talent shortage. There is a quantum skills shortage. The quantum workforce includes a wide range of skilled employees, such as quantum physicists, computer scientists, engineers, technicians and people with a business background. On average, quantum firms find one qualified candidate per three job openings. Most current jobs in quantum are still highly technical requiring academic specializations and PhDs. A total of 162 universities and institutions worldwide offer educational programs in quantum technology.[12] Despite these efforts, the quantum skills shortage will continue over the next five years and companies need to plan accordingly.

Commercial alignment. Market access and monetization will determine the winners. Quantum startups and scaleups compete to generate commercial applications that provide high ROI under the current tighter capital market conditions. Success cases include

quantum algorithms that improve discovery and design of new molecules and materials, optimization of complex aviation and automotive systems, accelerated training on machine learning algorithms, or improvements on existing AI, blockchain and cryptography. Companies need to align with the right partner that possesses a strong commercial framework.

Functional emphasis. Quantum computing is currently being used to address challenging areas in business, like vehicle routing, securities trading, medical image processing, drug discovery, green energy and cybersecurity. The new *noisy intermediate scale quantum* (NISQ) quantum devices provide competitive solutions to all these problems. Quantum annealers are already providing non-trivial solutions in optimization tasks, as exemplified by OTI Lumionics' work on quantum chemistry[13] and Ally Bank's work on index tracking.[14] Tensor networks can already accelerate complex deep learning tasks, with potentially disruptive effects across a wide range of applications.[15] Companies need to strategically select and identify the function that best impact their business transformation efforts.

Management of errors. The technical demands for handling errors in quantum systems pose challenges for physical hardware systems. Achieving scalable, fault-tolerant quantum error correction (QEC) is widely considered the ultimate goal for quantum computing. Companies and management teams need anticipate errors and have fallback measures in place, at least until error-free quantum computers will be fully developed.

Regulation and global standards. As the quantum potential grows, policy makers are creating new policies to enhance this technology and mitigate risks. Regulation includes principles such as 'common good,' accountability, inclusiveness, equitability, accessibility and transparency. The U.S. recently passed a new executive order with a roadmap to transition all federal agencies to post-quantum cryptography in 2035. Companies need to stay up to date with regulatory changes in the industry.

The identified challenges make it necessary for companies to make strategic changes in their business models and management systems to heighten the chances of success in their business transformation efforts.

4. Roadmap to Quantum Excellence

The authors recommend five approaches for managers pondering the adoption of quantum in their organizations:

1. **Know your destination**. With so many options and directions to choose from towards a business transformation journey, it is easy to lose sight of the end goal. Outlining clear and specific objectives on what needs to be achieved with quantum computing is a sensible first step.

2. **Prepare for the journey.** Successful companies in quantum have developed expertise in-house and deployed employee training programs to overcome the severe skill shortage in the sector. External firms can provide services and consulting, however it is paramount to involve internal employees in the early stages of the project. Boeing, for instance, successfully cultivated a strong internal team that led them to focus resources on their quantum R&D efforts. With the help of quantum companies like IBM, their engineers are exploring quantum algorithms to reduce computational complexity and materials design costs used for components like wings and fuselage, which can have up to 100,000 variables.[16]

3. **Navigate bottlenecks.** Start by identifying high-value problems that are creating bottlenecks that slows down the application process. BMW asked their engineers to identify bottleneck problems that constrained design and manufacturing. They created a working group that partnered with quantum computing companies and universities to better understand the catalytic chemical reactions in fuel cells.[17] Aircraft manufacturer Airbus focused on value when it launched a global Quantum Computing Challenge in 2018 to test quantum technologies to optimize aircraft loading. The winning service provider developed an algorithm, using quantum annealing, aligned with Airbus's strategic goals such as higher revenues, less fuel burn and lower operating costs.[18]

4. **Explore strategically.** Leading firms are currently exploring potential quantum computing applications to be first adopters. JP Morgan is testing post-quantum cryptography. In 2022, the Bank of Canada developed a quantum algorithm to simulate a complex, evolving economic network that produced solutions for the design of future policy interventions to protect economic stability.[19] This bold move by the bank turned quantum computing —a potential threat— into an asset advancing their mandate.

5. **Examine new territories.** Do not simply try to accelerate existing solutions through incremental gains in quantum computing capabilities. Instead, to make an impactful business transformation think 'outside the box' and examine new arenas and approaches to solving intractable problems. A key question to ask is "which quantum computing direction would lead to the greatest transformational impact?"

5. Concluding thoughts

A foray into quantum computing may appear daunting and out of reach for many companies. A few firms who boldly ventured to use the approach to find innovative solutions or gain a pioneering advantage have been rewarded with remarkable business transformation. The transformation journey however is not without peril. Lack of vision, poor planning, and inadequate resources can leave a firm lost. A successful transformational journey requires courage when facing the unknown and the flexibility to shift gears and change direction when needed.

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interacting with the external world, leading to a probability range associated to the results obtained upon observations of the quantum system.

3. 'Quantum-inspired' algorithms are based on tensor networks, which are a family of techniques derived from aspects of quantum mechanics, such as algebraic compression, that are applied to modelling or simulations done on a classical computer. These are available from quantum software companies via the cloud, and at a click through Amazon Web Service and Microsoft Azure marketplace within the next year. Quantum-inspired computing involves digital computers with special architecture able to calculate quantum-formulated problems, offered by companies like Fujitsu, Hitachi or Toshiba.

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