Ministry of Foreign Affairs

Collected White Papers
NL-UK collaboration on key-enabling technologies

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COLLECTED WHITE PAPERS

NL-UK COLLABORATION ON KEY-ENABLING TECHNOLOGIES

This document contains white papers resulting from several calls published by the Netherlands Innovation Network UK (NIN UK) in 2023/2024.

By providing funding for these white papers NIN UK aims to stimulate Dutch and British organisations to explore potential partnerships and to highlight interesting bilateral innovations and R&D initiatives.

NIN UK has a strong focus on key enabling technologies such as AI, semiconductors, quantum, and integrated photonics. Papers on these topics as well as on related technologies or the intersection of these technologies are therefore of most interest, but occasionally other innovation topics are also considered.

Priority is given to papers that demonstrate a clear contribution to deepening partnerships or a contribution to relevant technology developments. The papers should always include an aspect of cooperation between the Netherlands and the UK on key enabling technologies.

Contents:

Optimizing Wind Farm Efficiency With Quantum Technology

WHITE PAPER

Artificial Brain

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1. Introduction

As the world increasingly pivots towards sustainable energy solutions, wind energy promises a cleaner and greener future. Wind farms are crucial for harnessing the kinetic energy of wind, contributing significantly to reducing greenhouse gas emissions and combatting climate change. However, harnessing the full potential of wind energy has its challenges, with inefficiencies often hindering optimal system performance.

Traditional simulation and optimization techniques face limitations in accurately predicting the intricate dynamics of wind farm layouts, turbine designs, and overall energy output. Quantum simulation and optimization, powered by the unique capabilities of quantum algorithms, help in taking a leap forward in harvesting wind energy. These quantum algorithms can navigate the complexity of wind patterns, turbine interactions, and environmental factors with better precision, in less time, using lower compute resources.

2. Challenges in Designing Efficient Wind Energy Systems

There are multiple challenges in designing efficient wind energy systems.

We list a few of these challenges:

Suboptimal wind farm layout: The layout of wind farms is crucial for maximizing energy production. Poorly placed turbines can lead to interference and reduced efficiency.

Inefficient wind turbine designs: Environmentally, inefficient turbines contribute to an under utilization of available wind resources. They are less capable of harnessing energy from a broad range of wind speeds, particularly in low-wind scenarios. Many wind turbine designs are not aerodynamically or aero-acoustically optimized, resulting in lower energy conversion and structural issues such as vibrations, fatigue, and noise pollution.

Intermittent wind patterns: Wind energy production relies heavily on consistent wind speeds, but patterns can be unpredictable, leading to fluctuations in energy output.

Wake Effect: Wake effects play a crucial role in shaping the efficiency of turbines downstream in the context of power production within a wind farm. When the wind encounters a turbine, it creates a wake—a region characterized by reduced wind speed and increased turbulence—downstream of the turbine.

This wake poses a significant challenge for downstream turbines, as they experience lower wind speeds and altered wind flow patterns. The reduced wind speed diminishes the kinetic energy available for power generation, directly impacting the efficiency of downstream turbines. Furthermore, the turbulent nature of the wake introduces additional mechanical stress on the downstream turbines, potentially leading to increased wear and tear.

3. Limitations of Classical Computing

Computational demands in engineering designs are escalating due to the simulation of multiple physical phenomena. Complex Multiphysics simulations play a crucial role in engineering applications as they encompass various physical phenomena and incorporate algorithmic and architectural perspectives. The success of these simulations depends on mathematical analysis, computational complexity, and architectural considerations.

However, as wind turbine problems grow in complexity, classical computers face challenges in efficiently solving realistic Multiphysics applications. Optimization problems, especially those classified as NP (non-deterministic polynomial time) due to the abundance of constraints and conditions, pose even greater difficulties for classical computers to find exact solutions. Consequently, there is a need for alternative computational approaches that offer innovative problem-solving techniques in the engineering sector.

Classical computing techniques face formidable challenges in the optimization of wind farms, particularly in two critical domains: wind farm layout optimization and yaw optimization for wake steering.

3.1. Challenges in Wind Farm Layout Design

Wind farm layout optimization aims to strategically position turbines for minimal wake effects and maximal power output. Wake interactions, where the turbulence generated by an upstream turbine impacts the performance of downstream turbines, pose a significant challenge. Classical methods encounter difficulties in accurately predicting and mitigating the effects of wakes on downstream turbines.

Classical algorithms may struggle to account for the dynamic nature of wakes under varying wind conditions, leading to suboptimal layouts. Incorporating wake effects into the optimization process is crucial for maximizing power production, and classical methods may fall short in achieving the necessary precision. Addressing these challenges requires advanced algorithms capable of dynamically adapting layouts to minimize wake losses and enhance overall energy extraction efficiency.

3.2. Limitations in Yaw Steering Adjustment

Classical computing encounters significant setbacks in optimizing yaw for wake steering and maximizing wind farm power production. The intricate nature of wake interactions, influenced by dynamic wind conditions, poses a significant challenge for classical algorithms. Classical methods often struggle to adapt turbine yaw angles promptly and effectively to changing wind directions, hindering their ability to mitigate wake effects. The computational intensity required for assessing complex wake interactions and optimizing yaw angles overwhelms classical computing capabilities, leading to suboptimal solutions.

Moreover, classical approaches may lack the real-time responsiveness crucial for achieving optimal power production through wake steering. The lag in computational adjustments restricts their effectiveness in minimizing wake interference between turbines. Additionally, classical methodologies may not adequately account for asymmetric wake effects and uncertainties in wind farm inflow conditions, limiting their precision in optimizing yaw angles for both power output and turbine structural integrity. The inadequacies of classical computing in these crucial aspects underscore the pressing need for advanced computational paradigms, such as quantum computing, to unlock the full potential of wind farm optimization.

4. Introducing Quantum Simulation and Quantum Optimization

4.1. Quantum Simulation

Quantum Algorithms and Quantum Computing facilitate the emulations of physical systems behaviors or paradigmatic quantum-mechanical models. With emulation of physical systems, it can solve many previously intractable problems to go beyond the limitations of classical computing algorithms.

A quantum computer is powerful enough to simulate molecular statuses, structures, or the interplay between these molecules – tasks that even binary supercomputers cannot complete. This emulation capability promises a highly accurate model-based simulation tool by using Quantum Generative Design.

Quantum Generative Design can explore better, and efficient designs based on the input design goals provided by engineers and designers. Additionally, it allows adding multiple parameters and constraints in design manufacturing which can reduce the noise pollution while improving aerodynamic efficiencies. Quantum Generative Design technology is a game-changer, transcending the limits of traditional aerodynamic focus to integrate aeroacoustics optimization, hence, promising more wind energy yield while reducing noise generated from wind turbine blades.

In the context of wind energy systems, quantum simulation can be used for:

Modeling complex wind patterns: Quantum simulation can analyze vast amounts of data and simulate different wind patterns, enabling accurate predictions and optimization of energy production.

Predicting energy output with higher accuracy: Quantum simulation can help forecast energy output more accurately, minimizing discrepancies caused by varying wind conditions. This allows for better planning and efficient grid integration.

Optimizing turbine placement: By analyzing the characteristics of a specific area, quantum simulation can determine the optimal placement of wind turbines within a wind farm, considering factors such as wind direction, speed, and local topography.

Designing more aerodynamic and stable wind turbines: Quantum simulation can optimize wind turbine designs to make them more aerodynamic, reducing drag and improving energy conversion efficiency. Additionally, it can help aeroacoustics leading to improved structural stability, minimizing vibrations, fatigue, and noise pollution.

4.2. Quantum Optimization

Quantum optimization exploits quantum parallelism and entanglement to explore a vast solution space simultaneously. This capability is particularly powerful in addressing complex optimization problems, such as those encountered in wind farm layout and power production. Classical computing methods often struggle to navigate the intricacies of turbine placement and dynamic adjustments needed for optimal power extraction.

In wind farm optimization, quantum algorithms can evaluate numerous potential turbine configurations simultaneously. This allows for a more comprehensive exploration of layout possibilities, accounting for factors like wake interactions and environmental variability.

Quantum optimization, therefore, offers the promise of identifying optimal turbine positions with high accuracy, significantly enhancing power production efficiency. In wind farm optimization, this means achieving solutions with higher accuracy and efficiency compared to classical methods. By rapidly exploring and refining potential layouts, quantum optimization holds the potential to unlock precise turbine configurations that maximize energy output while minimizing wake interference.

5. Quantum Solutions: Navigating Specific Use Cases Through Simulation and Optimization

5.1. Use Case 1: Quantum Generative Design for optimized Wind Turbine blades.

Renewable energy sources like wind farms are gaining importance due to their environmental and economic benefits. Being the key component in wind energy systems like wind farms, wind turbine blades and their performance is critical for efficient power generation.

Due to the metal and wind interactions on Wind turbine blades, these are the most critical components to design possess several challenges. It has a significant impact on power generation efficiency and noise production.

Importantly, proper balance between structural integrity and weight of the blades are also important to consider. These multi-objective optimization problems become more challenging when aeroacoustics optimization is also required to reduce noise generated from Wind turbine blades. Moreover, it is essential to meet the strength and stiffness criteria of Wind turbine blades, and aerodynamic requirements to produce sufficient torque.

Quantum Generative Design for optimized wing design can reduce wind turbine noise with better aerodynamic designs and reduce noise generated from the wind turbine blades. Compared to conventional design optimization problems, this problem requires aerodynamic and aeroacoustics optimization simultaneously. Specifically, such design criteria make it more complex and time-consuming for classical algorithm-based design optimization methods.

The core of our approach is a novel quantum optimization algorithm that exponentially reduces the computational time while ensuring enhanced accuracy. Development of a gradient-based quantum optimization algorithm enables us to explore a broader design space compared to classical methods, allowing for more innovative and efficient design solutions. This computational power will be harnessed to target a significant improvement in aerodynamic efficiency while drastically reducing the noise levels for wind turbines.

Computational limitations of classical algorithms can be overcome through quantum algorithms capable of simultaneously optimizing both aerodynamics and aeroacoustics. This dual optimization represents a significant technological leap.

By utilizing the unprecedented computational speed promised by quantum algorithms aided by highly accurate model-based simulation tools, we target a significant improvement in aerodynamic efficiency and a 10-15% reduction in noise pollution for wind turbines.

Our quantum-based approach allows simultaneous optimization of both aerodynamics and aeroacoustics, something not feasible with existing solutions. Aerodynamic efficiency is of critical importance in this project for several interconnected reasons that have wide-ranging implications for both the wind energy sector and society at large.

Improved aerodynamic efficiency directly translates to greater energy yield from each wind turbine. This not only bolsters the economic viability of wind energy projects but also accelerates the broader transition to renewable energy sources, aiding global efforts to mitigate climate change.

An aerodynamic wind turbine can operate effectively under a wider range of wind conditions. This enhances the reliability and consistency of wind energy generation, making it a more dependable component in a diversified renewable energy portfolio.

5.1.1. Shape, Size and Structural Optimization for designing erodynamic and aero acoustic wind turbine blades.

Turbine blades are essentially airfoils similar to those used in industries like aerospace, automotive and race cars. Design optimization finds the optimal material layout of a given structure by rearranging the material within the domain. It is classified into size, shape, and topology optimization based on the problem's complexity. Topology optimization plays a significant role in achieving more efficient designs for wing turbine blades can be obtained with next-generation additive manufacturing technologies, departing from traditional rib-spar wing constructions.

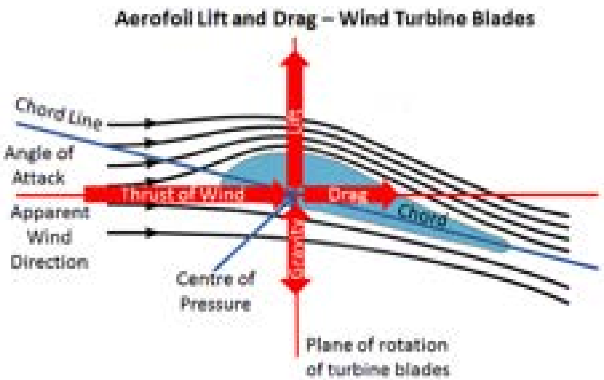

Figure: Drag and lift on wind turbine airfoil design

The shape and weight of the blades play a significant role in capturing wind energy efficiently. Topology optimization is key for designing lighter blades without compromising on the structural strength. However, computational challenges for simulations arise when dealing with high aspect-ratio of the blades, which require conventional density-based topology optimization methods to discretize the problem domain uniformly.

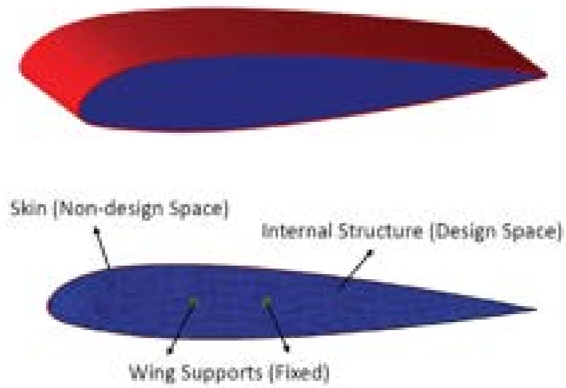

Figure: Complex geometry and boundary conditions of Airfoil

The above image shows design space in blue, which is required to be discretized in the above optimization method. The complex geometry and boundary conditions turn the problem into a large-scale design optimization problem. Similarly, high aspect ratio domains of the blade create more complex and harder-to-model design spaces. This limits the effectiveness of traditional classical optimization algorithms and classical computers that need an advanced solution.

Another limitation of the classical approach is that it reaches local minima instead of global minima, indicating that more efficient designs could be explored and exploited within the design process. Additionally, classical optimization methods require more iterations to get optimal results for a given air foil design, which demands more computing resources, such as GPUs and CPUs. Classical algorithms on classical computers demand more efficiency regarding the computing resources required while still delivering accuracy in topology optimization tasks

The Quantum-Inspired approach utilizes the principles of quantum computing, such as interference, superposition, and entanglement, to process information. By emulating these principles, the Quantum-Inspired approach allows for simultaneous searching of a larger solution space, leading to better-optimized results over classical solutions, faster convergence speed, and minimizes requirement of computing resources.

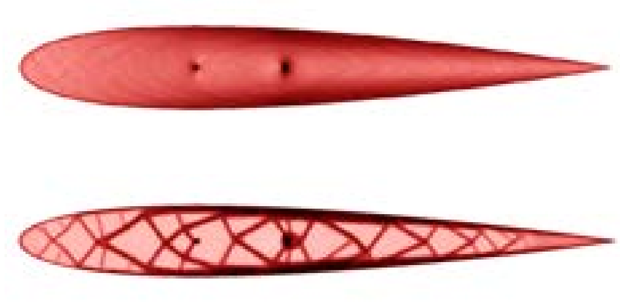

Figure: Airfoil with unintended structures removed to achieve weight reduction and volume minimization

Topology optimization based on Quantum Inspired Design Optimization (QIDO) removes materials from unintended structures, meeting the demands for low-volume structures, which increases the efficiency of the wind turbine components as shown in the image above.

A pilot use case done by BQP through this approach optimized an airfoil with 18% better optimization compared to traditional methods and resulting in an estimated 40% reduction in cost saving.

QIDO based solver can handle complex design problems, such as minimization of the total weight of the structure and finds global minima for obtaining optimal airfoil designs.

> **"BQP's pilot optimized an airfoil with 18% better results than traditional methods, leading to an estimated 40% cost reduction."**

5.2. Use Case 2: Wind farm Layout Optimization

Wind farm layout optimization encounters a significant challenge with classical computing due to its complicated nature.

Maximizing the power output from wind energy systems stands as a paramount challenge, with the inter-turbine wake interactions often proving a formidable adversary for conventional methodologies. Traditional approaches, grappling with the complexity of turbulent wakes, find themselves shackled when it comes to dynamically adapting layouts in the face of ever-changing wind conditions.

The computational intensity required for optimizing within the vast expanses of large wind farms adds yet another layer of complexity to an already intricate ballet.

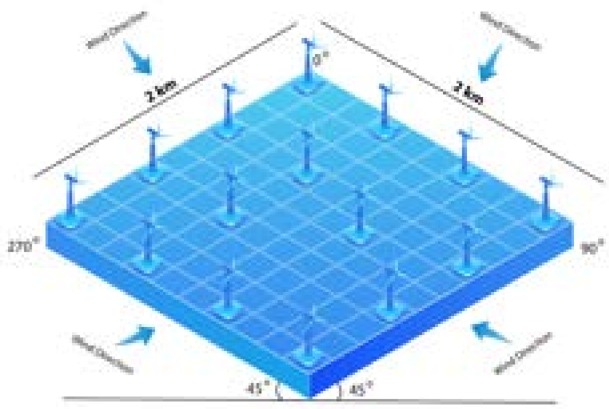

Figure: Optimizing wind farm layout

To overcome this, we turn to Quantum optimization techniques which presents a transformative approach to address these challenges. Leveraging the principles of quantum parallelism, the quantum algorithm explores multiple potential turbine layouts simultaneously.

When planning a new wind farm, several factors come into play, like the wind farm's boundaries, different wind conditions, directions, and the desired layout shape.

The main goal is to optimize power production, achieved by developing an objective function that navigates through these diverse constraints to find the best layout.

In the quantum optimization process, the arrangement of wind turbines is carefully considered. The algorithm explores the various iterations of the wind farm layout, paying close attention to the interactions between turbines, commonly known as wake interactions. What makes quantum optimization unique is its ability to explore all possible layouts simultaneously, a capability that classical methods lack. This quantum process ultimately reveals the most efficient layout—one that optimizes power production while adhering to the specific constraints of the chosen location's topography.

Armed with this quantum-derived optimal layout, engineers receive a practical blueprint that surpasses the limitations of classical computations. This blueprint, crafted within the given constraints and considering the unique topography of the deployment site, becomes a clear guide for bringing wind farms to life. Whether it's in the open sea or a complex landscape, the quantum-derived optimal layout provides engineers with a robust tool to create optimized wind farm configurations, pushing the boundaries of what is achievable in the pursuit of sustainable and efficient power production.

5.3. Use Case 3: Wake Steering Through Yaw Optimization

Optimizing power production through wake steering via yaw optimization is a pivotal use case in wind farm management. Each wind turbine is equipped with a yaw system, crucial for maximizing power output by ensuring the turbine constantly faces the wind. Given the dynamic nature of wind directions, a control system continuously adjusts the turbine's yaw angle to align with the prevailing wind direction. This adjustment minimizes wake effects on downstream turbines, thus enhancing overall efficiency. The challenge arises when determining the optimal yaw angles for a given wind direction scenario within an already established wind farm.

Wake effects play a crucial role in shaping the efficiency of turbines downstream in the context of power production within a wind farm. When the wind encounters a turbine, it creates a wake—a region characterized by reduced wind speed and increased turbulence—downstream of the turbine. This wake poses a significant challenge for downstream turbines, as they experience lower wind speeds and altered wind flow patterns. The reduced wind speed diminishes the kinetic energy available for power generation, directly impacting the efficiency of downstream turbines. Furthermore, the turbulent nature of the wake introduces additional mechanical stress on the downstream turbines, potentially leading to increased wear and tear. Addressing and mitigating the effects of wake interactions is pivotal for optimizing the overall power production efficiency of a wind farm, making it imperative to consider wake dynamics in the design of optimization processes.

In this optimization problem, the goal is to identify the yaw angles that maximize power production efficiency for a specific wind direction, wind speed, and other technical parameters of the turbines. The range of yaw angles, for instance, 0 to 31 degrees for each turbine in a farm, leads to an exponential increase in potential combinations as the number of turbines grows. Classical optimization techniques grapple with computational complexity, considering both the expanding number of yaw angles, wind turbine combinations and the intricate wake interactions between turbines.

Quantum optimization emerges as a transformative solution. By leveraging quantum algorithms, this approach allows for the simultaneous exploration of a vast sample space of yaw angles, considering variables such as wake interactions, wind direction, and other technical constraints. Quantum optimization operates in real-time, efficiently analyzing the expansive solution space and providing an optimal set of yaw angles for the wind farm under specific wind conditions.

As wind directions change throughout the day, classical techniques would necessitate a prolonged duration to generate a suboptimal solution set for yaw angles.

Conversely, quantum optimization excels in delivering precise and accurate yaw angle sets within seconds. Moreover, this quantum algorithm can be executed multiple times as the wind direction changes, ensuring the wind farm consistently operates at peak efficiency throughout the year. The quantum advantage lies not only in speed but in the ability to swiftly adapt to changing conditions, providing a revolutionary approach to enhancing wind power production efficiency.

The use of quantum optimization for wake steering through yaw optimization in wind farms is a game-changer. The exponential increase in possible yaw angle combinations, coupled with the intricate wake interactions, makes this a complex problem for classical techniques. Quantum optimization not only addresses these challenges efficiently but also offers real-time adaptability, ensuring that wind farms can achieve and sustain peak power production under varying conditions.

5.4. Use Case 4: Predictive Analysis using Quantum Machine Learning (QML)

Wind turbines play a vital role in harnessing renewable energy and reducing our dependence on fossil fuels. However, surface defects on wind turbine blades can compromise their protective coatings, leading to reduced operational efficiency and increased maintenance costs. To address this issue, predictive analysis using image-based machine learning has been proven effective in detecting surface defects. However, traditional machine learning algorithms face computational bottlenecks when dealing with large datasets. This is where quantum machine learning comes into play, offering a solution that provides efficient processing and quick model generation.

Traditional image-based machine learning algorithms require significant computational power and time-consuming training processes to develop accurate defect detection models for wind turbine blades. These limitations can hinder the scalability and practicality of implementing quality control systems for large-scale wind farms.

Quantum machine learning, on the other hand, provides a unique approach to overcome these challenges. By harnessing the power of quantum computing, quantum machine learning algorithms can process complex datasets and perform computations much faster than classical algorithms. This enables efficient training of quality control models specifically designed for surface defect detection on wind turbine blades.

One of the key advantages of quantum machine learning is its ability to handle large datasets efficiently. The speed and processing power of quantum computers enable quicker analysis, reducing the time required to train accurate defect detection models. This enhanced efficiency not only saves valuable time but also enables real-time defect detection and facilitates prompt maintenance actions.

Another advantage is the ability of quantum machine learning algorithms to handle high-dimensional data. Surface defect detection on wind turbine blades involves analyzing intricate patterns and features within images. Quantum machine learning algorithms can effectively capture these high-dimensional characteristics, allowing for accurate classification and detection of defects.

Additionally, quantum machine learning offers the potential for increased accuracy in defect detection compared to traditional machine learning algorithms. By leveraging quantum algorithms, these models can consider complex relationships between data points that may not be easily captured by classical algorithms. This enhanced accuracy leads to more reliable and robust quality control systems for wind turbine blade maintenance.

5.5. Use Case 5: Wind Turbine Surface Defect Detection

Implementing a quantum machine learning quality control model for wind turbine surface defect detection follows a similar process to traditional machine learning. First, a large dataset of defect images needs to be collected. These images should include various types of surface defects found on wind turbine blades, ensuring that the model can learn and recognize different types of imperfections.

Next, the dataset is processed using quantum algorithms to extract relevant features and patterns. Quantum machine learning models can efficiently analyze this data and build a representation that captures the distinctive characteristics of surface defects on wind turbine blades.

Once the model is trained, it can be deployed in real-time quality control systems, providing prompt defect detection and facilitating proactive maintenance activities. By leveraging the speed and efficiency of quantum computing, wind farms can significantly improve their quality control processes, minimize downtime, and optimize the operational efficiency of their turbines.

6. Exploring results and Stakeholder Benefits: An In-Depth Analysis

Transitioning from classical optimization techniques to quantum optimization signifies a paradigm shift driven by the shortcomings of the former. Classical methods, burdened by sluggishness and escalating computational complexity as variables in the sample space increase, fall short in delivering prompt and optimal solutions. Quantum optimization, in contrast, emerges as a swifter and more accurate alternative, promising optimal solutions that maximize wind farm power production. The shift is not merely about speed but a fundamental transformation in the approach to solving complex optimization problems.

In the realm of wind farm layout optimization, the quantum advantage becomes evident. By inputting the objective function, constraints, and technical parameters into the quantum algorithm, the exploration of the sample space involves considering wake interactions between turbines. The quantum solution, unlike its classical counterpart, comprehensively explores the entire sample space in a single iteration, providing an optimal layout that minimizes wake effects and maximizes wind power production. The inherent parallelism of quantum computation enables a holistic evaluation that classical techniques struggle to achieve.

Moving beyond layout optimization, the exploration extends to the use case of wake steering through yaw optimization. Here, the positions of wind turbines and the yaw angle ranges are crucial inputs to derive an optimal solution set that minimizes wake effects. Quantum optimization takes on the growing sample space, which grows with increasing number of yaw angles, and t number of turbines. Despite causing misalignment in certain wind turbines, the collective outcome is an augmented wind power production for the entire farm. Quantum optimization, with its capacity to swiftly navigate the evolving sample space, yields precise and optimal solutions, surpassing the limitations of classical techniques.

The quantum-driven approach not only accelerates the optimization process but also promises increased wind power production when compared to baseline scenarios. The synergy of exploring vast sample spaces, accounting for growing variables, and dynamically calculating wake interactions positions quantum optimization as a transformative force in the realm of wind farm management. The results obtained are not only optimal but indicative of a quantum leap in efficiency, marking a significant stride towards harnessing wind energy with unprecedented accuracy and sustainability.

The incorporation of quantum optimization into wind farm management marks a pivotal advancement for stakeholders in the energy sector, delivering transformative advantages over traditional classical techniques.

Classical methodologies, characterized by slow-paced results and suboptimal solutions, impose limitations on stakeholders' ability to make timely, well-informed decisions. Quantum optimization, however, revolutionizes this landscape, providing stakeholders with not only faster but also optimal outcomes.

For energy sector stakeholders, the accelerated pace of obtaining optimal solutions through quantum optimization translates into heightened operational efficiency and responsive decision-making. This agility is particularly crucial for adapting swiftly to dynamic changes in wind conditions and turbine configurations, ultimately maximizing energy output. The financial implications of increased power production are significant, enabling stakeholders to reap higher financial returns from their wind energy projects.

The societal impact of quantum-driven increased power production extends beyond economic considerations, contributing to a more sustainable and eco-friendly energy ecosystem. Stakeholders, including energy companies, governments, and the public, stand to benefit from a cleaner and more abundant energy source. Moreover, the economic gains resulting from optimized power production bolster the competitiveness of wind energy in the broader market, attracting additional investments and fostering growth in the renewable energy sector.

Crucially, the financial benefits for stakeholders in the energy sector are substantial. The quantum-driven increase in power production enhances the revenue potential of wind farms, allowing stakeholders to capitalize on higher energy yields. This economic advantage positions wind energy projects as lucrative investments, providing stakeholders with the opportunity to obtain higher amounts of revenue. The financial returns garnered from optimized power production not only contribute to the economic viability of individual projects but also align with global initiatives promoting the transition towards sustainable and renewable energy sources.

The introduction of quantum optimization into wind farm management not only accelerates decision-making and enhances energy output but also brings about significant financial gains for stakeholders.

The ability to obtain higher amounts of revenue due to increased power production underscores the transformative impact of quantum techniques, propelling the energy sector towards a more prosperous and sustainable future.

> “Quantum optimization accelerates solutions for energy stakeholders, boosting operational efficiency and agile decision-making.”

7. Business Opportunity

The global wind energy market was valued at US$ 81.31 billion in 2022 and is projected to be worth around $211.85 billion by 2032 with a registered CAGR of 10.10% from 2023 to 2032 [2]. Furthermore, the broader renewable energy market, was valued at $881.7billion in 2020, and is projected to reach $1,977.6 billion by 2030, growing at a CAGR of 8.4% from 2021 to 2030 [3], highlights the immense growth opportunities when integrating advanced technologies, such as quantum computing.

In this rapidly evolving landscape, the global quantum computing market, valued at around USD 840.37 million in 2023, is expected to expand significantly, with a projected CAGR of 28.8%, reaching approximately USD 8,208.89 million by 2032 [4]. This market growth opens vast business opportunities for stakeholders in both the energy and quantum software sectors.

Specifically, the integration of quantum optimization into wind farm management presents lucrative avenues for quantum software companies specializing in developing algorithms for wind farm optimization.

The emerging business model fosters a collaborative relationship between energy stakeholders and quantum software companies. The latter provides advanced quantum algorithms tailored for optimizing wind farm layouts and effectively managing wake effects through yaw optimization. This partnership catalyzes technological innovation while aligning with the global commitment to sustainable energy practices.

As the quantum software industry matures, it carves out a niche in wind farm optimization, representing a market with substantial growth potential. By positioning themselves as leaders in this domain, quantum software companies can form enduring partnerships with energy stakeholders, significantly contributing to the evolution of renewable energy practices.

Ultimately, the integration of quantum optimization into wind farm management establishes a symbiotic relationship between energy companies and quantum software firms. This collaboration places energy companies at the forefront of sustainable solutions and propels quantum software companies into a thriving market, thereby fostering innovation and driving positive change in renewable energy.

> **“The global wind energy market, valued at $81.31B in 2022, is projected to reach $211.85B by 2032 with a CAGR of 10.10%.”**

8. Conclusion

In conclusion, our exploration into the integration of quantum technology into wind farm management reveals a transformative shift from traditional classical techniques to a quantum-driven approach. The limitations of classical methodologies, characterized by sluggishness and suboptimal outcomes, become stark when contrasted with the speed, precision, and efficiency offered by quantum optimization.

Through the lens of critical use cases the inadequacies of classical techniques are evident. Quantum technology emerges as a game-changer, navigating complex sample spaces and intricate wake interactions with unparalleled speed and accuracy. In the realm of wind farm layout optimization, quantum algorithms explore the entire solution space in a single iteration, providing optimal layouts that maximize power production. Similarly, in the case of wake steering through yaw optimization, quantum optimization dynamically calculates optimal yaw angle sets, efficiently addressing the growing sample space and varying wind conditions.

The societal benefits are profound. Increased power production resulting from quantum technology not only bolsters the financial returns for stakeholders in the energy sector but also aligns with global sustainability goals. The ability to harness wind energy more efficiently contributes to a cleaner and more abundant energy source, fostering a greener future. Moreover, the optimized power production enhances the competitiveness of wind energy in the broader market, attracting investments and promoting growth in the renewable energy sector.

From a business perspective, this paradigm shift represents a significant opportunity. Energy stakeholders stand to gain by embracing quantum-driven wind farm optimization, securing a competitive edge and realizing higher financial returns. Simultaneously, quantum software companies specializing in the development of advanced algorithms for wind farm optimization have a burgeoning market to explore. By offering tailored solutions, these companies can not only contribute to technological innovation but also establish themselves as leaders in a niche market with immense growth potential.

In essence, the integration of quantum technology into wind farm management not only addresses the limitations of classical techniques but also paves the way for a more sustainable and lucrative future. This quantum-driven evolution is a testament to the synergy between technological innovation, societal benefits, and viable business opportunities. As stakeholders increasingly recognize the transformative potential, this collaborative journey promises to redefine the landscape of renewable energy practices, propelling us towards a future where clean and efficient energy is not only a necessity but a quantum-powered reality.

9. References

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[4] https://www.expertmarketresearch.com/reports/quantum-computing-market

10. About Artificial Brain and BosonQ Psi

Artificial Brain:

Artificial Brain is a quantum computing software company developing optimization solutions for Space, Energy, Aviation, and Defense. Artificial Brain has a global presence with offices in the USA, Netherlands, and India and ability to tap into diverse markets, talents, and resources.

Artificial Brain also emerged as one of winners of the Prototype Track in the Deep Tech Category of the highly regarded myEUspace competition, organized by the European Union Agency for the Space Programme (EUSPA). Artificial Brain's innovative quantum algorithm, designed to optimize real-time scheduling for multiple Earth Observation Satellites (EOS), clinched the victory, promising to bring groundbreaking solutions in the integration of EU space data with cutting-edge technologies like Artificial Intelligence (AI) and Quantum Computing.

Furthermore, their contributions to sustainability challenges have been featured in Nature India, underscoring their commitment to leveraging quantum-based technologies for global sustainability [1].

BosonQ Psi:

BosonQ Psi (BQP) is a SaaS simulation software startup leveraging Quantum algorithms that accelerate advanced simulations to design high-quality products faster and more economically. Its product, BQPhy, is integrated with Quantum algorithms which can overcome complex simulations that are expensive, and time-consuming for enterprise end users from mobility, energy, construction, biotech sectors among others.

BQP currently brings state-of-the-art simulation capabilities integrated with Quantum-inspired algorithms, which can run on today's HPC (High Performance Computing) and provide near-term value. It is also working on hybrid-classical algorithms for future simulation capabilities. The company is part of startup programs by IBM, Intel, AWS (Amazon Web Services), Microsoft, TCS (Tata Consulting Service), and Tech Mahindra. It has raised over a million dollars from investors and government grants. It is part of Alchemist Accelerator, Hustle Defense Accelerator program by Griffiss Institute, and UK Innovate's net zero program.

THANK YOU

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Unlocking the full potential of cancer treatments using targeted radionuclide therapy through Netherlands-UK partnerships

King's College London
Erasmus MC University Medical Center Rotterdam
Radiobiology of MRT European Working Group
Kingdom of the Netherlands

Executive Summary

Investigating the optimal use of radioactive cancer-targeted drugs presents a unique opportunity to improve cancer treatment, by personalising it to an individual's needs, treating cancer that is spread throughout the body, or has become resistant to other therapies. By combining the strengths of the UK and Netherlands in science and health technologies and prioritising funding towards this research area, there is now the opportunity to accelerate research into optimising these radioactive drugs, and for both nations to maintain global leadership in this field.

Radioactive cancer-targeted drugs stand at the forefront of a paradigm shift in cancer treatment, holding unparalleled promise to not only target cancer volumes visible through scans but revolutionize the very landscape of oncological care by killing tumour cells spread across the body, even those that are resistant to other treatments.

By harnessing the precision of radioactive elements, radioactive cancer-targeted drugs offer a transformative avenue, enabling personalized, potent, minimally invasive treatments that transcend the limitations of conventional cancer therapies and can spare healthy tissues. They can redefine the boundaries of what is possible in cancer treatment.

Expansion of cancer treatment options to enable long, high quality lives for patients is a health priority set out by both the Netherlands and the UK in policy and national manifestos.

This white paper outlines three strategic recommendations to achieve this ambition:

- Strategically allocate funding to enhance mechanistic understanding of targeted radioactive drugs.
- Facilitate UK-NL clinical trials in targeted radionuclide therapies.
- Coordinate training initiatives.

Radioactive drugs can be used to specifically deliver a radiation dose to cancer cells which produces a therapeutic effect.

They can be used to treat not only the disease areas identifiable on medical scans but also can specifically target the microscopic tumour deposits spread across the body, involved in progression of the disease.

Despite its proven efficacy in clinically approved therapies, there is opportunity to fully unlock the potential of these treatments by better understanding the biological mechanisms and radiation dose delivered by these therapies and consequently why some patients respond better than others.

To optimise existing treatments and develop new personalised ones, many unknowns still need to be investigated.

With the development of novel radioactive drugs currently undergoing exponential growth and the global market expected to grow 5-fold by 2032.

Now is the time to invest in the science to ensure that when these new radioactive drugs are implemented, we get the treatments right for patients.

This paper identifies and addresses existing challenges and unknowns in radioactive cancer-targeted drugs and showcases the possibilities afforded through collaborative research in radiobiology and dose measurement between scientists and organisations in the Netherlands and UK.

The big challenge

One in two people will be diagnosed with cancer at some point in their life [1]. As described in the UK Department of Health and Social Care Policy paper [2], "good health should be fundamental to all our lives" and cancer has been selected as one of the top six conditions which should be focussed on.

Targeted radionuclide therapy, or molecular radiotherapy, which is an injected radioactive cancer-targeting drug, can be used to treat a wide range of cancers, including prostate cancer, thyroid cancer, neuroendocrine cancer, and neuroblastoma, which is a cancer type affecting mainly children.

Although remission is possible in some situations, these treatments are mostly used at a late or final stage treatment to alleviate symptoms with patients often having run out of other (curative) options to treat their cancer. The recent success seen with targeted radionuclide therapy has prompted an exponential growth in development of novel radioactive drugs with small and big pharmaceutical companies pushing forward with their latest developments.

> **"However, these novel therapies are being used clinically, or proposed for clinical use, without fully unlocking their potential to becoming curative options for cancer patients. For this to happen, many scientific unknowns in radiobiology, dosimetry, and radiation response still need to be answered, which require additional investment in scientific research."**

Photo by Vincent Blinde

[1] Longer, better lives: A manifesto for cancer research and care; https://www.cancerresearchuk.org/sites/default/files/cruk_manifesto.pdf
[2] Major conditions strategy: case for change and our strategic framework, https://www.gov.uk/government/publications/major-conditions-strategy-case-for-change-and-our-strategic-framework/major-conditions-strategy-case-for-change-and-our-strategic-framework--2

Research involving collaboration between the Netherlands and UK is a pivotal step for joint progress in targeted radionuclide therapy.

Now is the time to combine efforts and maximise progress in this field, to best help treat cancer patients and cement the role of the Netherlands and the UK as world-leading experts in this vital area of research. This is well-aligned with both the UK's Life Sciences Vision [3], and the first national action plan to treat cancer in the Netherlands [4].


Photo by Vincent Blinde

[3] Life Sciences Vision, https://assets.publishing.service.gov.uk/media/612763b4e90e0705437230c3/life-sciences-vision-2021.pdf
[4] The Dutch Cancer Agenda, https://nederlandskankercollectief.nl/update/persbericht-eerste-landelijke-actieplan-kanker-gelanceerd/

Both the Netherlands and UK possess highly skilled individuals across the disciplines relevant to targeted radionuclide therapy, particularly in radiobiological and dosimetry studies. This partnership is rooted in established collaborations (albeit in low numbers) and a rich tapestry of complementary research skills and expertise, both in the lab and clinically.

> ***It holds the potential to revolutionise the field of targeted radionuclide therapy. It will also ensure a comprehensive approach to targeted radionuclide therapy research and application.***

Combining efforts, rather than acting as two siloed countries, will increase the impact and positive outcomes from targeted radionuclide therapy, and leverage existing similarities in the Netherlands and the UK healthcare systems and clinical trial structures. Partnering would also allow for better and faster clinical trials due to increased recruitment possibilities across each country's diverse population.

Each nation has complementary skillsets from which the other country would benefit.

Photo by Vincent Blinde

The UK's expertise includes:

- The foundation for precise metrology, ensuring accuracy in dosimetry, activity standards and nuclear decay data, from the National Physical Laboratory.

- Drawing from its nuclear industry experience, the UK National Nuclear Laboratory has successfully identified nuclear waste as a source of therapeutic radionuclides (e.g. radioactive lead) or starting materials and demonstrated these can be separated, which have both health and environmental benefits.

- A rich heritage of radiation biology and radiation medicine research, in particular optimisation of fractionation and dose-response effects for external beam radiation contributing to a deep understanding of the field and providing a solid foundation for applying this to advancements in radionuclide therapy.

The Netherlands' expertise includes:

- The current NRG facility, and FIELD lab stand as a cornerstone in nuclear research, providing a platform for advancements in targeted radionuclide therapy research and application through providing isotopes.

- The new PALLAS nuclear facility in the Netherlands, which is being supported and funded by the Government of the Netherlands demonstrating their commitment to the field of nuclear medicine which includes radionuclide therapy.

- A Dutch dosimetry core unit, showcasing a centralised approach to dosimetry research, which is pivotal in ensuring standardised and accurate dose measurements.

- A heritage in targeted radionuclide therapy research, with the [^{177}Lu]Lu-DOTA-TATE molecule developed in Erasmus Medical Center Rotterdam for the treatment of neuroendocrine tumours, which has contributed significantly to the success and opportunity now available for targeted radionuclide therapy.

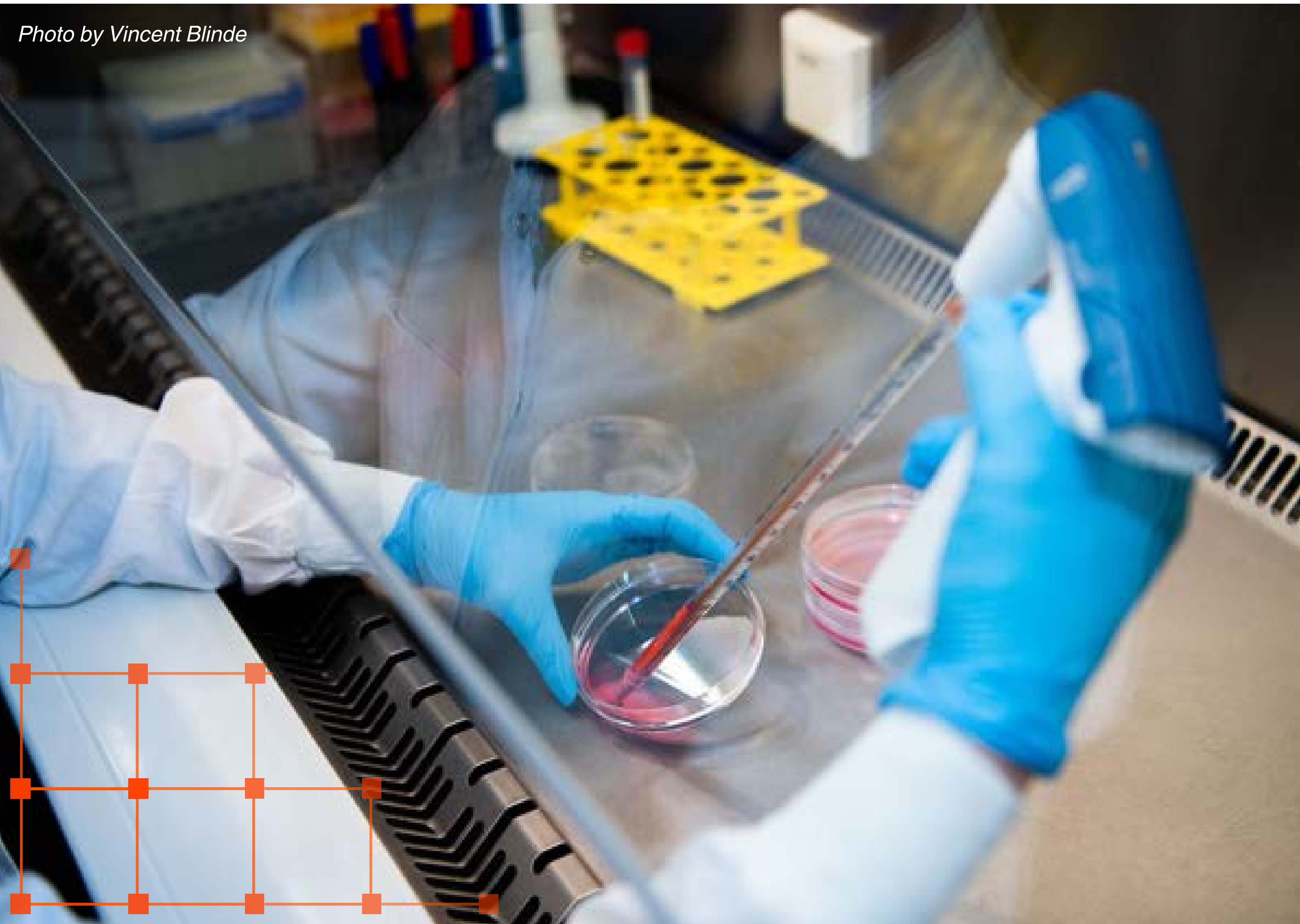

Photo by Vincent Blinde

How do we make this a reality?

We aim to secure commitment from both governments that this is a research area which should be prioritised for funding because of its vast potential to enable targeted radionuclide therapies to be developed into earlier stage and possibly curative options for cancer patients. A synergistic collaboration between the Netherlands and the UK could expedite the realisation of this goal and elevate the global research standing of both nations.

While the Netherlands and UK possess complementary strengths, the collaborative efforts in advancing targeted radionuclide therapy face hurdles. We have created three strategic recommendations to accelerate achievement of this ambition.

1. Strategically allocate funding to enhance mechanistic understanding of targeted radioactive drugs.

A joint strategy and implementation of resource allocation could ensure investments are strategically directed towards radiobiological and dosimetric research in targeted radionuclide therapies with the aim of significantly improving patient outcomes.

Facilitating joint lab-based and clinical research projects and trials, exchange research projects between labs and countries, and access to radionuclides will further support the production of agents for clinical trials.

Photo by Vincent Blinde

2. Facilitate UK-NL clinical trials in targeted radionuclide therapies.

This will foster cross-country collaborations and ensure the smooth delivery of trials. It could accelerate trials particularly in rare diseases by expanding the patient pool. We propose the process for sharing radioactive drugs, patient tissue or blood samples between sites should be streamlined.

Furthermore, defining and sharing protocols and best practices will improve reproducibility and promote standardization, safeguarding the authenticity of research outcomes. Striving for a balanced partnership with pharmaceutical companies is essential, where research objectives align with the broader goals of advancing targeted radionuclide therapies to improve patient outcomes.

3. Coordinate training initiatives.

There is great skills gap in radiobiology, radiochemistry and dosimetry, and in clinicians using these treatments. Joint initiatives must be developed to enhance training, ensuring a skilled workforce capable of driving advancements in targeted radionuclide therapies. We recommend creating Centres of National Excellence to deliver research and clinical trials. Additionally, fostering knowledge exchange through reciprocal visits by principal investigators, students, and researcher associates to labs will enhance the collaborative learning experience.

Photo by Vincent Blinde

How can you help?

This collaborative call to action invites stakeholders, policymakers, scientists, and funding bodies to actively engage in the implementation of these recommendations.

Therefore, you can:

- ***Promote this message and paper***
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Cybercrafters: Transforming cybersecurity through vocational training

Jan 2024

Cybercrafters:
Transforming cybersecurity through vocational training

Revnext
D5-IQ
Immersive Labs

Cybercrafters

This white paper aims to establish the most effective strategy for strengthening our cybersecurity defences amidst evolving security challenges and technological advancements, all while addressing the shortage of specialized talent. The authors assess the potential benefits and challenges associated with expanding cybersecurity training to a wider audience and research how this approach compares with the current reliance on a limited pool of experts. They leverage the experiences in cybersecurity training from their respective countries, which to some extent shape their perspectives on cybersecurity education. The Netherlands, recognized for its emphasis on digital literacy and proactive cybersecurity measures, advocates for a comprehensive approach that integrates education with practical application. In contrast, the UK often emphasizes the cultivation of collaborative partnerships among academia, government, and industry, highlighting the significance of diverse, interdisciplinary education. The convergence of these varied perspectives and the insights gained from previous training initiatives results in the creation of an innovative cybersecurity curriculum called Cybercrafters.

Introduction

For years, a pronounced gap in expertise and capabilities has persisted in the realm of cybersecurity, unveiling a pressing need for professionals in this field. While employers, educators, and governments have demonstrated various efforts to bridge this cybersecurity void, recent figures have shown that the gap is nevertheless widening. Research from Goupil et al. (2022) describes the current cybersecurity landscape as an ongoing “arms race”. This development is compounded by concerns regarding the qualifications of the existing workforce, which are often seen as inadequate when compared with the demands from the industry (Goupil et al., 2022).[1]

The mentioned "arms race" is driven by the swift adoption of a wide array of new digital technologies in sectors like manufacturing, healthcare, education, and within the IT sector itself. This expansion broadens the attack surface that requires protection. In addition, the cybersecurity landscape is becoming increasingly complex and vulnerable due to the pervasive integration of technological trends such as the Internet of Things (IoT), Artificial Intelligence (AI) and, although still in a preliminary stage, quantum computing.[2] These developments are outpacing the growth of skilled experts capable of safeguarding data, networks and systems against increasingly sophisticated threats.

In light of the widening void, there is an urgent need to evaluate the current approach towards strengthening cybersecurity expertise and capabilities. This means foremost assessing whether the content of existing cybersecurity training needs updating and analysing the effectiveness of current training methods. However, it remains to be seen whether this process of evaluating and reevaluating is enough. As we have not been able to catch up on the expertise and capabilities deficit for many years, it might be time to ask a more fundamental question; are we actually training the right people? More specifically, should we persist in primarily depending on a limited

[1] Goupil, F., Laskov, P., Pekaric, I., Felderer, M., Dürr, A., & Thiesse, F. (2022). Towards Understanding the Skill Gap in Cybersecurity. ACM Digital Library. https://doi.org/10.1145/3502718.3524807
[2] "TUM: Emerging Technologies and the Future of Cyber Security." Technical University of Munich. Accessed January 15 2024, https://www.lll.tum.de/emerging-technologies-and-the-future-of-cyber-security/

number of highly specialized cybersecurity experts, or should we redirect our attention towards providing basic cybersecurity education to a wider portion of the population? If we choose the latter, the implications of such a change in direction can be profound as it directly impacts on our collective ability to effectively defend against the evolving spectrum of cyber threats.

How we have been tackling the cybersecurity skills gap so far

In addressing the question of whether a more robust training approach is required, it is imperative to reflect on our current methods. Unsurprisingly, both the UK and the Netherlands are contending with similar challenges regarding the scarcity of cybersecurity professionals. Examining their individual responses offers valuable insight into the efficacy of the strategies adopted

Treating the skills gap as a Human Resources-problem

In both countries, efforts have been made to attract, recruit, and retain individuals with the necessary skills and expertise through various HR-campaigns. In the UK, for example, the CyberFirst Programma was initiated in 2022 by the National Cyber Security Centre (NCSC) to identify and nurture young talent. The Programme offers courses and workshops, student bursaries, degree courses and apprenticeships. Similarly, in The Netherlands government and private sector have sponsored summer schools[3], networking opportunities, challenges and certifications.

What these efforts have in common is that they respond to *existing* vacancies for cybersecurity experts. The common denominator in these vacancies[4] is that they look for candidates with specialized, foremost university-educated, backgrounds. In addition, these vacancies often require years of experience or specific qualifications in cybersecurity topics that are relatively new and unexplored. The risk of this HR-focused approach is that it is based on the idea that the specialists needed are there, but just have not yet been found.

Investing in training a small group of specialists

Both the UK and The Netherlands have invested significantly in training and developing a select group of highly specialised professionals. In the UK, organisations such as GCHQ and the National Cyber Security Centre play key roles in cultivating elite talent for national security purposes. British initiatives tend to be academic in nature. The UK government, for example, supports and collaborates with cybersecurity centres of excellence, research hubs, and innovation clusters hosted by academic institutions. Furthermore, government agencies often collaborate with academic institutions on joint research projects, initiatives, and partnerships focused on cybersecurity.

The Netherlands has specialised units within its central government and military focused on fostering cybersecurity talents. Often the elite specialists for these units require a strong background in IT before they are thoroughly trained in practical topics such as vulnerability assessment, pentesting, digital forensics, cryptography and incident response. In addition, extra schooling in current laws and regulations, new developments in AI and quantum computing, as

[3] For example the ICSSS: https://summerschoolcybersecurity.org
[4] Based on a 2023 search for cybersecurity vacancies on Linkedin, Indeed, as well as Gov.Uk and WerkenvoorNederland

well as audit processes are given. While these approaches have undeniably contributed to expanding the pool of experts in both countries, it comes at high costs and requires long-term investment. As there is no multiplier effect for these specialists, this approach has not been able to address a broader need for foundational cybersecurity skills across various sectors.

Providing certification to define specialisms

Research from The Netherlands Cybersecurity Strategy 2022-2028 stresses the critical need for a robust cybersecurity workforce. The strategy also highlights a significant cyber resilience disparity among organizations, with some well-prepared and others lagging, exacerbating vulnerabilities (Ministry of Justice and Security, 2023).[5] One of the solutions mentioned in the strategy is to look to essential cybersecurity frameworks and standards to help define and certify cybersecurity specialisms, for example through the Dutch National Certification Authority. The UK government doesn't have a specific certification program solely administered by the government for cybersecurity specialists. However, there are several recognized certifications in the field of cybersecurity that are widely accepted and valued by employers in the UK.[6] Furthermore, both countries have numerous initiatives focused getting employees training on the job, but also on registering informal cybersecurity qualifications as to better match job descriptions.[7] These initiatives not only facilitate training but also aid in recognizing informal qualifications, thereby aligning better with job descriptions and requirements.

The different processes of certification fit the forementioned HR-view on the cybersecurity gap and the prioritization of cybersecurity specialists. The question remains, however, whether this approach fits the nuanced and varied needs of diverse organizations.

Increase outsourcing

Outsourcing of cybersecurity roles has been a prevalent strategy in both the UK and the Netherlands. This practice has provided organisations with access to specialised skills and helped alleviate the immediate pressure on in-house teams. The feasibility of outsourcing or remote work depends on factors such as the nature of the task, the level of trust required, and compliance considerations. While this type of outsourcing is increasingly common in the private sector, the public sector seems more hesitant towards this approach. In general outsourcing has focused on cybersecurity tasks seen as continuous or repetitive such as automatic scanning and detection as well as patch management. Overall, outsourcing these types of tasks has reduced costs, and improved operational efficiency, allowing organizations to focus on their core business objectives. However, it's essential for organizations to carefully evaluate outsourcing providers, establish clear

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[5] Ministry of Justice and Security. (2023). Netherlands cybersecurity strategy 2022-2028. In National Cyber Security Center. National Cyber Security Center. https://english.ncsc.nl/publications/publications/2022/december/06/the-netherlands-cybersecurity-strategy-2022-2028

[6] Such as the Certified Information Systems Security Professional (CISSP) offered by (ISC)², the Certified Ethical Hacker (CEH) offered by the EC-Council or the Certified Information Security Manager (CISM) offered by ISACA,

[7] In the UK, for example, cybersecurity training and qualification recognition are promoted through:

1. The UK Cyber Security Council, which offers comprehensive information on the cybersecurity profession, including career development across its specialisms.
2. The Cyber Security Breaches Survey 2023, which encourages organizations to enhance their defenses and promote cyber awareness.
3. The UK Government's e-learning courses, developed in collaboration with industry leaders, to help staff understand online threats and protect business resources.

communication channels, and ensure compliance with legal and regulatory requirements when outsourcing cybersecurity tasks.

Acceptance and risk mitigation
In both the UK and the Netherlands, there is a shared recognition of the complexity and persistence of cybersecurity challenges. This has led to an increase of organisations adopting a risk-based approach, thereby accepting a certain level of vulnerability while focusing resources on protecting critical assets. This pragmatic approach acknowledges the impossibility of achieving absolute security but aims to manage and mitigate risks to an acceptable level. This approach is not so much tackling the cybersecurity skills gap problem as it is accepting it.

Diversifying training and capabilities across a wider spectrum of forces

For several years our companies have been involved in cybersecurity training for various target groups. Revnext, as a high-tech consultancy firm, trains high-level management of governments, listed companies, critical infrastructure and NGOs in the areas of cybersecurity governance, high-tech innovation, strategic development and performance improvement. D5-IQ, a firm specialized in "train as you fight" gamified cybersecurity training, leverages AI-powered solutions to bridge the gap between theoretical knowledge and practical skills. Drawing from defence organization experiences, D5-IQ trains, measures, tracks, and enhances the skills of large groups, ensuring preparedness for evolving cyber threats. Bristol-based Immersive Labs, a specialist in AI-powered gamified learning, offers dynamic platforms with hands-on labs that integrate AI to create real-world scenarios. These labs, such as "AI for business", "Quantum Cryptography" and "AI fundamentals", demonstrate how AI can address complex challenges across various industries.

Our three companies have been joining forces in several cross-channel cybersecurity training cooperations. Throughout these cooperations, the forementioned insights from existing Dutch and British initiatives have helped us explore new approaches to achieve necessary cybersecurity skills and expertise. While the UK and the Netherlands have undoubtedly made significant strides in developing specialised talent and leveraging external resources, we find a growing recognition that not everyone is cut out to be a specialist and that there is only so much a small group of specialists can achieve. This recognition is reflected in a wider trend within the cybersecurity field that sees cybersecurity becoming less of a separated silo within the field of IT, or a specialized niche, and more of an overarching cross-sectoral necessity.[8]

[8] The Dutch Government's I-Strategy recognizes the increasing reliance of organizations on IT. It emphasizes placing IT at the core of operations for efficiency and effectiveness[1]. This is outlined in their agenda point 'I in het hart'[1]. For more details, please refer to the following sources:

1. I-Agenda/I-strategie Rijk
2. Kamerbrief I-strategie Rijk, actualisatie routekaarten, evaluatie I-agenda
3. I-strategie Rijk 2021-2025 - Digitale Overheid
4. I-strategie Rijk 2021-2025 | Beleidsnota | Rijksoverheid.nl
5. Strategische I-agenda Rijksdienst 2019-2021, editie 2020

Numerous IT specialists would concur that they have spent years advocating for cybersecurity to be prioritized in boardrooms. It is only recently that we observe boardrooms actively addressing the issue and, moreover, cascading cybersecurity initiatives downward throughout the organization. More than before, we are seeing HR-staff, for example, being trained in privacy protection and anti-phishing campaigns, finance officers in detecting CEO fraud, and network architects and developers in secure coding. In addition, various vocational professions are slowly acknowledging and embracing the cybersecurity components in their fields.

Inspired by this trend, we have been extending our specialist training portfolio and broadening our target groups. In doing so we have focused our efforts to train more people to obtain basic skills in the cybersecurity domain instead of dedicating our efforts solely on a small group of specialists. A significant justification for this action is the recognition that if our nations are indeed engaged in what has been termed an "arms race," the necessity of expanding training is advocated by both military strategists and contemporary cybersecurity realities. We learn from modern military conflicts that asymmetric warfare requires a broader approach because relying on only a small number of specialized forces can make us vulnerable. By diversifying training and capabilities across a wider spectrum of forces, organizations can better adapt to and counter asymmetric threats while reducing vulnerabilities associated with reliance on specialized units.[9]

Custom Cybersecurity Training: A Growing Need

In both the UK and the Netherlands, we have observed an increase of requests for customized training sessions originating from diverse industries and participants who do not fall under the typical category of IT or information security personnel. These requests go beyond standard phishing tests or awareness sessions, but require tailored solutions related to the field potential participants are working in. Examples of projects executed by our organizations in The Netherlands include:

- Hands-on security training for car mechanics who specifically requested to learn about secure updates, protection of industrial control systems and rules about data protection. Further requests consisted of training modules focused on the maintenance of (electric and hybrid) cars;
- Hands-on security training for employees in the metal electro- and installation industry where employees are handling ever more IoT (Internet-of-Things) devices such as solar panels, charging stations and domotica (home automation);
- Tailored trainings for lawyers, notaries and clerks to raise awareness of relevant cyber security risks and developments that could impact their business operations.

The demand for customized cybersecurity training is evident even at the educational level for young individuals. MBO (vocational) schools and their students consistently express a need for sector-specific cybersecurity knowledge that is applicable to real-world scenarios. Since 2016,

[9] Pulling Levers, Not Triggers: Beyond Direct and Indirect Approaches to Irregular Warfare." Modern War Institute, West Point. Accessed december 2023, [https://mwi.westpoint.edu/pulling-levers-not-triggers-beyond-direct-and-indirect-approaches-to-irregular-warfare/]

Revnext experts have regularly given guest lectures on various cybersecurity topics at MBO and HBO (applied sciences)-schools. During Covid-19 Revnext, D5-IQ and Immersive Labs supported MBO students in the Amsterdam region in providing access to practical hands-on cyber security labs which they could access from home. In addition, Revnext offers an in-depth Digital Forensic Research module (CSI-010: Digital Forensics) twice a year free of charge for MBO students in the Rotterdam region. In this module MBO-teachers work together with various guest lecturers from government and business. However, the demand from MBO schools for these guest lectures has increased over the years, with the result that there is now a waiting list for participation. The increased popularity is due to

- The demand from (potential) employers for cybersecurity qualities,
- The lack of substantive experts and relevant content among the existing teachers within the various practical training courses, and
- The intrinsic interest and motivation of MBO students to participate in to explore these topics in depth[10]

In addition to these projects in The Netherlands, Immersive Labs has worked with the UK military not only to help train their cyber security specialists, but also allow and stimulate other military personnel to use their cyber security trainings platform. This not only improves their skills but has the side benefit of being able to identify IT and cyber security talent in branches of the military which are not or only limited involved with cyber security activities.

Introducing Cybercrafters

Based on our shared (and cross-Channel) experiences with diverse training methods and new target groups, we are now looking to extend the lessons from these projects and build up a curriculum that ties in directly with practical training courses and their competency profiles. This curriculum, the Cybercrafters program, is directed at different vocational sectors.[11] An important difference with our activities thus far is that, although the Cybercrafters program incorporates the lessons learned from the various tailored trainings, the focus is on forging a sustainable connection within the existing MBO (Netherlands) or further education (United Kingdom) curriculum. Attention is thus directed towards ensuring the measurability of learning objectives and establishing a foundation for accreditation by the MBO/further education. To achieve this, the curriculum is closely aligned with the subject-specific content covered in existing practical training courses. Consider, for example, a focus on IoT safety within electrical engineering courses, a focus on automotive security for car mechanics and a focus on data protection and crisis management for caregivers. Cybercraft is the key word here. It is the fusion of manual construction processes, craftsmanship and digital tools: the combination of performance and creativity.

To develop the Cybercrafters curriculum, we are exploring the following steps:

- Collaborating with established vocational sector educators such as MBOs and/or industry associations to initiate discussions about implementing a Cybercrafters program tailored for students and working professionals in specific industries.

[10] Over the past seven years, the CSI-010 modules have always been highly rated by students (average 8.5 out of 10) and well attended.

[11] See for instance https://www.onderwijsloket.com/kennisbank/artikel-archief/welke-niveaus-en-richtingen-zijn-er-binnen-het-mbo/ for different directions of vocational sectors that could benefit from a Cybercrafters curriculum.

- Crafting a comprehensive advisory report for each vocational sector, including potential suggested curriculum enhancements based on the aforementioned steps.
    - Engaging in discussions regarding the desired cybersecurity knowledge and skills aligned with existing competency profiles.
    - Determining appropriate learning objectives through collaborative discussions.
    - Assessing the needs associated with existing practical training courses.
- Development of Cybercrafters curriculum based on the advisory reports for specific vocational sector
    - The Cybercrafters curriculum will include a generic part for all courses (e.g. how to protect oneself) as well as course-specific parts for various practical courses (e.g. specific threats/risks for industries and roles)
    - This curriculum contains both theoretical elements and practical components (the Cyber Crafts)
    - The curriculum also includes guest lectures/stories from the field as well as a test / challenge / exam for students and professionals to pass and get a certificate
- Pilot project of the Cybercrafters project:
    - Implementation of the curriculum in at least one vocational course
    - Monitoring of learning objectives and progress
    - Exam / test / challenge for students and professionals
- Evaluation of the pilot
    - Pass rate of participating students and professionals, student/professional satisfaction, teacher evaluations, level of achieved competencies and successful implementation of new teaching methods
    - Suggestions for improvements and adjustments to the project

A closer look at learning objectives, the variety of practical courses and certification for the Cybercrafters program

In addition to looking at existing competency profiles of vocational courses, Revnext and D5-IQ will use the NIST/NICE Framework as a basis to look at desired and relevant cyber security skills.[12] This is an international framework to define cyber security roles and underlying cyber security tasks, knowledge areas and skills. Starting bottom-up relevant specific knowledge areas, tasks and skills from the NIST/NICE framework can be used to identify relevant learning objectives and skills for the Cybercrafters curriculum. In comparison the UK's Cyber Security Body of Knowledge (CyBOK)[13] could also be used to identify relevant skills for the Cybercrafters program. Based on identified desired knowledge areas, skills and tasks relevant theoretical concepts as well as practical courses can be selected focused on these skills.

In terms of practical courses and teaching methods D5-IQ, Revnext and Immersive Labs have a range of proven methods at its disposal from in class training to demonstrations to gamified and immersive training simulations. Different methods can be used keeping in mind their pros and cons. Theoretical knowledge will likely be taught mainly via in class trainings as well as via guest lectures (stories from practice why specific concepts are relevant to understand). For practical

[12] https://www.nist.gov/itl/applied-cybersecurity/nice/nice-framework-resource-center
[13] https://www.ncsc.gov.uk/section/education-skills/cybok

purposes trainings can be via demonstration (for participants to see and slightly experience for instance see how a remote device could be taken over or password cracked) to the use of simulated immersive environments where they could bring theory into practice themselves (e.g. take over a (test) IoT device yourself, catch wifi signals sent by a device, etc.). The use of demonstrations and practical environments increases retention of knowledge and stresses importance of theoretical concepts (as well as increase the fun of learning for participants).

Revnext and D5-IQ can use the award winning platform of Immersive Labs in addition to various demo's and course material from their own Cyber Security Academy to provide hands on practical labs and training environments.

Future steps: fast-track the required workforce transformation

According to Hatzivasilis et al. (2020), the importance of cybersecurity training has grown exponentially in organizations. This has expanded the potential target group for cybersecurity training, ranging from basic users seeking knowledge of the current threat landscape and defense mechanisms to security experts requiring hands-on experience in responding to security incidents (Hatzivasilis et al., 2020).[14] As we recognize and have analyzed this trend across the Channel, we believe that we present a compelling case for the Cybercrafters program, an initiative spearheaded by Revnext, D5-IQ, and Immersive Labs. The ultimate goal of this program is to cultivate a more knowledgeable and diverse workforce proficient in cybersecurity craftmanship, equipped to understand threats and advancements in the field. This not only benefits the organizations they serve, ranging from NGOs to businesses to government institutions, but also societal organizations, by ensuring alignment with current requirements and enhanced protection against cybersecurity risks. And the benefits do not stop here. From a business perspective, it may be more cost-effective for us to train a larger group of individuals with foundational skills rather than exclusively investing in specialized experts, especially when considering constraints such as limited time and budget.

Recognizing the critical role of cybersecurity in today's digital landscape, we are committed to launching this project in both the Netherlands and the UK. When acquiring cybersecurity knowledge and expertise is likened to an arms race, the evolution of the cybersecurity workforce necessitates a broad defence strategy rather than narrow specialization. We, therefore, passionately appeal for partnerships and support from the Dutch and UK governments. Together we can fast-track the required transformation through the Cybercrafters program, paving the way for a more secure digital landscape for everyone. Let's join hands in fostering cybercraftmanship!

[14] Hatzivasilis, G., Ioannidis, S., Smyrlis, M., Spanoudakis, G., Frati, F., Goeke, L., Hildebrandt, T., Tsakirakis, G., Oikonomou, F., Leftheriotis, G., & Koshutanski, H. (2020). Modern aspects of Cyber-Security training and continuous adaptation of programmes to trainees. Applied Sciences, 10(16), 5702. https://doi.org/10.3390/app10165702

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The Alan Turing Institute

Advances in Privacy-Enhancing Technologies and Finance

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Privacy-enhancing technologies (PETs) have the potential to fundamentally change the way we think about data sharing in the future. Both for The Netherlands Organisation for Applied Scientific Research (TNO) as for The Alan Turing Institute (Turing) the most important research fields for PETs are health care and finance. In this article we focus on research on the use for PETs in finance, some interesting application areas and future research. We first describe what we consider to be PETs. Then we will go into some future research areas in finance. We end with some potential disrupters for the future of PETs.

1. Privacy Enhancing Technologies

Traditional data protection mechanisms, such as encryption and digital signature schemes, focus on the mitigation of threats from external adversaries; they ensure that data cannot be accessed by unauthorized entities. These techniques aim to protect data at rest and data in transit, and they implicitly assume that entities can be categorized either as internal, i.e., authorized to access the data, or as external. However, in our current digital society the situation is much more complicated. Many applications require confidential or sensitive data to be shared with entities that are not (completely) trusted. Hence, internal entities may exhibit malicious behaviour too, and only protecting against the malicious actions of external entities is no longer sufficient. This is where privacy-enhancing technologies (PETs) come into play. PETs aim to protect sensitive and confidential data in use against malicious actions by entities operating on the data. They try to minimize the amount of information that entities learn from operating on the data, thereby protecting privacy and confidentiality.

There exist a wide variety of PETs; some are already widely deployed in practice, while others show great potential but lack maturity. Some techniques make use of advanced forms of cryptography, while others use different mechanisms to achieve their goals. The following table lists a number of PETs that we consider to be important and powerful techniques in the protection of privacy and confidentiality.

PET	***Description* & Maturity**
Tokenization/ Anonymization/ Pseudonymization	*Replace a (personal) identifier by a (pseudo)random value.* These techniques are well established and widely used, for example, by Google. However, they suffer from the danger of inference attacks. Therefore, a combination with other PETs needs to be sought.
Multi-Party Computation (MPC)	*Cryptographic technique to allow multiple parties to analyse distributed data, without learning anything beyond the outcome of the analysis.* MPC is a promising technology and recent research has made practical use possible. Many start-ups have been picking up on the use of MPC lately. However, its success will strongly depend on legislation and standardization.

Homomorphic Encryption (HE)	*Cryptographic technique to allow computations to be performed on encrypted data.* HE is a somewhat mature technology, that can be used for different purposes, among which MPC. However, it still suffers from large computation times, especially for complicated AI algorithms. Also, for a breakthrough in HE, standardization is needed.
Zero-Knowledge Proof (ZKP)	*Cryptographic technique to prove the knowledge of secret data, or more generally to prove the veracity of a claim.* ZKP is an emerging technology, and numerous companies are working on ZKP systems. So far, they have mainly found widespread adoption in blockchain applications. More research is needed on promising other applications of ZKP.
Federated Analytics/Learning (FA/FL)	*Analyse distributed data, or train a machine learning model, (iteratively) at the source of the data, rather than collecting the data centrally.* FA/FL is an emerging and promising technology. However, it is in a relatively mature stage, because it cannot ensure privacy independently. FL is prone to inference, inversion and reconstruction attacks. The local model updates can be reverse engineered to reveal private and sensitive information. Thus, it needs more proof of concepts for integration with other PETs for a privacy-preserving employment. Moreover, FL is also prone to poisoning attacks in the presence of malicious participants. Thus, it needs to be rigorously investigated to guarantee robustness and security, in a malicious/competitive setting.
Differential Privacy (DP)	*Mathematical framework for outputting aggregated information, e.g., statistics, while limiting the information leakage on individual data entries.* DP is a mature PET but lacks the standards for integration and immediate employment. DP has a trade-off between privacy and utility. DP needs to be adopted/studied for specific applications, and data distribution, as deciding the privacy parameter (or budget) i.e., ε influences privacy-utility balance. The impact of an available neighbouring dataset should also be investigated. Moreover, DP may be only efficient in mitigating specific privacy attacks like membership, but it is still prone to property inference attacks.
Synthetic Data Generation (SDG)	*Generative a (random) dataset, based on sensitive and confidential data.* SDG is a still maturing technology, with significant promise. However, it needs more proof-of-concepts for a more realistic adoption. Synthetic data has a utility vs privacy trade-off. The more noise is added, it ensures more privacy, but leads to degradation of the utility. It has different challenges across various forms of data, like image, text and audio and video. Moreover, Synthetic data is not inherently private, and vulnerable to privacy attacks. Thus, SDG needs further improvement as well as integration with other PETs.
Trusted Execution Environment (TEE)	*Secure and isolated hardware environment to perform computations.* TEE is a mature technology. However, it still needs to be customised for each application, introducing a trade-off between security and performance. As the size of secure execution environment is very small and limited. Therefore, it requires strategies for the code placement, along with limiting the overheads in context switching, ensuring security.

2. Application Areas in Finance

Both for TNO and Turing the most important PET research fields are health care and finance. In both domains there are huge amounts of sensitive data, that cannot just be shared between different parties. In the first domain, there is a potential in using combined patient data from different sources to improve health care, for example by improving prediction models. Vertically partitioned data (different features from the same patients) of two hospitals can be combined to perform a regression model [2]. However, this data cannot be shared across institutions in raw form. Thus, PETs need to be adopted to forge a privacy-preserving collaboration among different healthcare institutions to achieve a better clinical research, drug discovery and precision medicine. Another potential useful PET in health care is synthetic data, in which Turing has developed a package SqlSynthGen (SSG) to generate syntactically accurate healthcare data [6]. SSG facilitates data generation irrespective of schema peculiarities.

For the area of finance, there are many application domains. There are different classes of application, such as Know-your-Customer (KYC) and Anti-money laundering (AML), but also identity management or financial markets [1]. In the first area, TNO has done some important work on privacy-enhancing AML. Together with banks, they have developed a secure risk propagation algorithm, that enable banks to follow risky money in the entire transaction network in a multi-party computation. This way, the banks move away from their limited view on their own part of the transaction network. On the other hand, privacy of sensitive data will be guaranteed because of the use of homomorphic encryption [3]. Turing has also done significant work on privacy-enhancing AML [11]. They have proposed solutions for AML systems together with banks across borders, abiding the regulations and compliances. They also performed a rigorous threat analysis for AML systems, considering all the stakeholders including third-party (like cloud service provider) involvement, in both multi-party settings and homomorphic domain.

In the future research of PETs in finance, three important areas are identified.

Algorithm fairness & PETs

Though fair machine learning itself is a rapidly developing field, it did not get much attention in finance yet [1]. In relation to PETs, one could distinguish two research directions. First of all, like any AI model, a PET model can give biased results. In the topic of finance this can have severe consequences for clients. For example, when using FL with multiple banks, it could be that all the banks hold some bias in their data. It may not be even considered bias locally, as it is suitable for those demographics. However, the bias gets induced to the local model updates, unintentionally. Still, it may be useful after aggregation, as local models from different sources with heterogenous data distribution will result in a fair global model. The question remains whether bias should be mitigated locally, or not. This motivates to ensure fairness as well as robustness to poisoning attacks. Moreover, a large heterogenous distribution also demands personalisation of the global model for the participating (banking) organizations.

A second research direction could be towards using PETs to access sensitive features in order to measure bias. Data scientists are on the one hand obliged to assess fairness in their model on sensitive features, while on the other hand they are not always allowed to use those features. [10] A privacy-enhancing system could offer a solution to assess fairness without needing to access the sensitive data or model. In this area, Turing has developed a post-processing bias mitigation technique, employing a model interpretation strategy, to find the model weights responsible for causing the bias. Through the selective pruning of only a few model weights, the model achieves group fairness in its predictions while still maintaining competitive accuracy levels [8], while using limited sensitive data.

Entity resolution

Entity resolution refers to data techniques that aim to uniquely resolve data to a real-world entity. This is very relevant in the fight against financial crime, because it requires accuracy in discovering specific entities in a large dataset. Some of the challenges around this topic might be addressed using PETs. For example, banks can securely exchange information to achieve more accurate entity resolution.

On the other hand, when using PETs with multiple banks, the use of entity resolution is much needed. For example, in the secure analysis on multiple transaction networks that was mentioned above, an entity resolution preprocessing might improve the analysis a lot. It also has applications in Anti Money Laundering (AML) Systems. Different branches of same bank, across demographics want to execute an unbalanced fuzzy private set intersection (PSI) over datasets across borders. Due to regulations, raw exchange of information is not allowed. Thus, it requires developing a PET-based scheme to facilitate fuzzy PSI. It also follows a strict threat model, where the matching records should only be known to the querying party. In this area, Turing has developed a novel privacy-preserving approach for fuzzy name matching for institutions across borders, employing fully homomorphic encryption [9].

Synthetic data generation (SDG)

Synthetic data can serve many needs, including augmenting data, counter-acting data bias, testing data pipelines and models, and protecting privacy. There are many existing methods implemented in open-source software libraries for creating tabular and time-series synthetic data which meets different requirements for fidelity and privacy.

However, data holders store large datasets in complex relational database schemas to optimize search, update operations and backup operations. These data holders would also like synthetic equivalents but there are unique challenges involved in creating synthetic data for relational tables.
For this purpose, Turing has developed SQLSynthGen (SSG) [6], a software package that can generate synthetic relational data to populate any given schema. By default, it creates data of extremely low fidelity and no privacy risk, that is only syntactically correct. This data already meets software testing needs and can be safely released publicly if the schema is public. Beyond the default settings, SSG can create higher fidelity data. This is achieved by enabling the user to specify exactly which marginals are extracted from the source data, and how they are used to inform the synthetic data. This allows for agile development with incremental fidelity improvements as needed, with transparency, auditability, and control over privacy risk at all stages. The user can also choose to use differential privacy to protect the marginals extracted from the source data.

Specifically for the research on better AML, you might not only need relational data. For example, for research on transaction graph algorithms, you might need synthetic transaction data which can be very useful. For this purpose, TNO is working on GraphBin [7]: an approach to generate synthetic nodes with features and directed edges. The edges reflect how the original edge probabilities depend on the node degree or other node-level features (including categorical and continuous domain attributes).

3. Potential disrupters for the adoption of PETs

The future adoption of PETs, not only in finance but also in other domains, will not only depend on scientific and technical progress. Likewise, regulation and the development of the market will be crucial for what the future of using PETs will look like.

Scientific and technical progress

Scientific progress in fields such as machine learning and cryptography plays a dual role, as they can both strengthen and weaken PETs. On the one hand, they pave the way for identifying vulnerabilities and designing more sophisticated attack models. On the other hand, they also lead to the creation of advanced encryption methods that enhance privacy protection.

Consider for example Federated Learning. Despite its design focused on safeguarding privacy, this technique is susceptible to various forms of attack, potentially eroding its privacy-preserving essence. Conversely, the same scientific progress that exposes these vulnerabilities also contributes to the advancement of stronger encryption methods, thereby bolstering privacy. New exploits and novel approaches may make current PETs vulnerable in the short term. However, in the long term, this evolving landscape may fundamentally shift how privacy is approached as new threats continuously develop and are countered.

Also, Fully Homomorphic Encryption (FHE) faces significant challenges. FHE marks a groundbreaking development in data security by enabling computation on encrypted data without the need for decryption, which ensures that data remains secure even during processing, surpassing traditional encryption methods. FHE paves the way for new possibilities in data sharing applications and computation outsourcing, previously unfeasible due to security concerns. However, one primary obstacle is the lack of standardisation, leading to potential issues in implementation. Additionally, the advent of quantum computing poses a new challenge. Quantum computers, capable of performing calculations at incredibly fast speeds, could potentially break many existing cryptographic protocols, including some elements of FHE.

From a business perspective, this evolving landscape presents opportunities for innovation and competitive advantage, as businesses at the cutting edge of PET development can leverage this as a market differentiator. Moreover, compliance with evolving privacy regulations becomes paramount, directly impacting the company's reputation and customer trust. Therefore, the company may need to increase investment in risk management and strategies to adapt to these evolving threats. For individuals, this changing landscape underscores the importance of awareness about privacy issues and data protection, including understanding the limitations of current PETs and potential trade-offs between enjoying digital services and maintaining personal privacy. Regulatory bodies, meanwhile, face the challenge of dynamic legal frameworks that can adapt to new privacy challenges while balancing the need to protect individual privacy and foster technological innovation.

Regulation

The regulatory environment plays a pivotal role in shaping the adoption and application of PETs, particularly when managing sensitive data in the finance and healthcare sectors. In finance, data protection laws such as the EU's General Data Protection Regulation (GDPR), the California Consumer Privacy Act (CCPA), and the UK's Data Protection Act require organisations to handle personal data with the utmost care, as well as data minimization, purpose limitation, and individual rights to access, rectify, and delete data. However, regulations like the Bank Secrecy Act of 1970 (BSA 1970) mandate financial institutions to disclose certain financial data to government entities to prevent financial crimes, creating a complex balance between maintaining privacy and the integrity of financial transactions [4]. Similarly, in healthcare, the Health Insurance Portability and Accountability Act (HIPAA) in the U.S. imposes rules for safeguarding sensitive patient health information, including requirements for the de-identification of data under specific circumstances [5]. Both sectors are increasingly relying on big data and analytics, but they are required to maintain a balance between maximising the utility of the data and protecting privacy.

This balance is where emerging PETs such as homomorphic encryption, differential privacy, and secure multi-party computation become critical for enabling data analysis without compromising individual privacy. However, a significant challenge arises from the regulatory frameworks, which often lack in recognising and integrating these advanced technologies, leading to legal uncertainty. There is an ambiguity in current privacy laws regarding the specificities of PETs, raising issues related to compliance and liability.

In today's interconnected world, cross-border data sharing poses additional challenges in aligning PETs with the varied and sometimes conflicting regulatory requirements of different jurisdictions and new laws and amendments. Tools such as privacy impact assessments (PIAs) and regular audits are crucial to demonstrate their compliance with such a dynamic regulatory landscape.

Commercial disruptor: Market dominance

Large tech companies like Google and advanced AI models like ChatGPT dominate the digital space. They have extensive control over vast amounts of data and influential power over industry standards, including privacy norms. The competing businesses may struggle to keep pace with the standards set by these dominant players, potentially leading to a less competitive market. Individuals, while initially benefiting from improved products, might eventually face limited choices and privacy concerns. Regulatory bodies face the challenge of ensuring fair competition and protecting consumer privacy, a task that becomes increasingly complex with dominant market players. In the short term, leading companies may be incentivized to develop and implement more effective PETs to maintain user trust and secure their competitive market positions. However, over time, there is a risk that their market dominance could hinder privacy innovation and lead to privacy standards favouring business models over user privacy.

To mitigate negative impacts, research is required to advance robust and trustworthy data-sharing frameworks. Such frameworks can foster opportunities for smaller enterprises and startups, enabling them to establish collaborations in a competitive landscape.

4. Future of PETs in finance

In this article, we have shown that that there is a potential for the use of PETs in the financial domain. It has also been observed that, no single PET guarantees perfect privacy under ideal conditions. There always exists a trade-off among privacy, utility and performance. Fairness, synthetic data and entity resolution are just examples of applications that can enhance the privacy of data use by financial institutions. Moving forward, the development and implementation of PETs in the financial sector depend on the regulations, scientific progress and development of the commercial market. For the adoption of PETs, we do not only need technology, but also regulation and market willingness. In order to get this willingness, we need a better understanding of risks and threats.

Furthermore, there is a need for greater collaboration between stakeholders in the financial sector, technology providers, regulatory bodies, and academia. Such collaboration can foster the development of standards and best practices and the design of appropriate PETs to address real-world privacy challenges.

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7th November 2024

Hardware for Educating Quantum Engineers

Joint NL-UK opportunities for fostering further cooperation on key technologies

Purpose

Quantum Technologies is a key area of innovation that unlocks disruptive capabilities not achievable by other means. Developing these as well as knowing how to apply it effectively will become a key differentiator in the economy of the future in a manner similar to the benefits provided by Computers, Internet of Things and Artificial Intelligence. To achieve this, significant resources in terms of time, materials, financing and in particular talent are required. This whitepaper explores the opportunities for utilising the strengths of the United Kingdom and the Netherlands in the context of cold atom quantum technology for education and accelerating research.

Summary

The Netherlands and the United Kingdom are both leaders in the quantum technology space, with deep understanding and expertise across its many platforms and application areas. The importance of skilled labour to achieving national strategies as well as key technology development is a major key factor to both. Initiatives and opportunities to address this is at an early stage and market potential found is in the hundreds of millions for the single application of hardware for educating quantum engineers. A set of recommendations that focus on enabling immediate and direct collaboration between the UK and NL is made, in line with the recently signed memorandum of understanding, with outcomes that will benefit both economies, delivery of their quantum strategies and technology development.

Introduction

The quantum technology market is nascent, but it is already a multibillion-euro industry today and is expected to grow over 15-fold by 2040 (McKinsey, 2023). Parallels are often drawn with the semiconductor industry and the advent of the transistor. Accurate numbers predicting the exact market vary significantly from study to study due to the high uncertainty and potential offered by quantum technology. The impact of performing previously impossible calculations, 1000x improvements in sensing sensitivity and unbreakable communication are some of the tantalising prospects offered and currently being explored in the sector.

Estimates put the potential economic impact to industries such as automotive, chemical, finance and life sciences at a value of $1.3tn by 2035. According to the latest McKinsey report in quantum technology, the respective markets for computing, communications and sensing is expected to be $93bn, $7bn and $6bn by 2040.

Technical University Eindhoven

The technical university of Eindhoven is a leading university in the development of quantum secure communication, and quantum computing using cold atom technology.

The quantum efforts have strong industrial goals: The TU Eindhoven is looking for the connection with the high-tech industry to create manufacturable, commercial quantum systems. To achieve this an infrastructure route is followed, with a quantum computer being developed which is externally accessible, a testing network for quantum communication accessible by industry and extensive connections to enable high-tech custom component manufacturing in the region for industrial partners and to enable national and international collaborative design/engineering, which has grown into a national activity called the quantum manufacturing alliance.

The university works with the higher vocational institute Fontys to provide master level education in quantum at both levels and provides re-education and specialist training for engineers through a talent and learning centre.

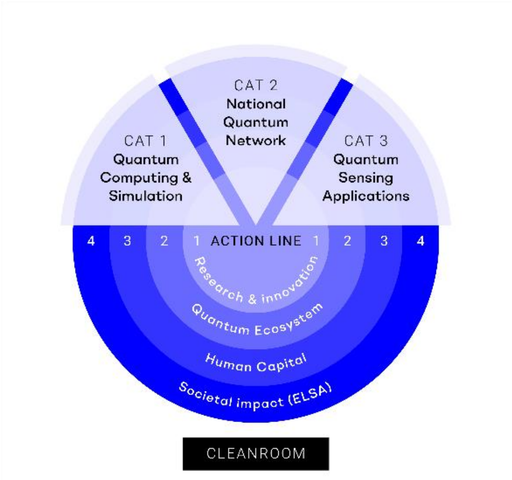
Aquark Technologies

Spun-out in 2021, Aquark Technologies looks to enable the future of quantum innovation by addressing the miniaturisation, robustness and scalability of cold matter-based technology. Based in Southampton, United Kingdom, the company has specialist knowledge in microfabrication and vacuum together with a unique and simplified method for trapping and cooling atoms. Dubbed a Supermolasses trap by the company, Aquark works to enable cold matter technology that can offer cutting edge precision for a device the size of a credit card.

Recognising the nascent, but disruptive nature that quantum technology offers, Aquark Technologies is embracing a holistic approach with a quantum system integration and ease access of hardware to support the growing ecosystem and missing talent pipeline.

Regions and Technology

The quantum landscape in the Netherlands



In the Netherlands, a significant portion of the funding for quantum developments is arranged through the Quantum Delta ecosystem, which is itself funded through the Dutch national growth fund mechanism for long-term economic development (Quantum Delta, 2024) (Quantum Delta, 2021). The Quantum Delta ecosystem contains 5 regions (**D**elft, **E**indhoven, **L**eiden, **T**wente and **A**msterdam - **DELTA**). Each region specializes in different technologies and industrial capabilities. A total of 615 million € has been dedicated to research, development and education of quantum systems as well as for the generation of collaborations with business, spin-off, collaboration and more through 3 catalyst programs funding quantum system development:

- CAT1: Quantum Computing,
- CAT2: Quantum Networking,
- CAT3: Quantum communication

and 4 action lines:

- AL1 (fundamental) research,

- AL2 national ecosystem development,
- AL3 workforce and education,
- AL4 ethics and society.

All activities in the quantum delta program are designed to be non-competitive and to support the activities in other CAT's, action lines and regions where possible. Each catalyst and action line has its own roadmap with dedicated goals and objectives.

Regionally the differences are large: Delft focuses on cryogenic systems with superconducting and spin qubits, with a startup base largely focused on quantum components such as chips, electronics, quantum links with several full stack system suppliers. In Eindhoven the focus is full stack systems, with efforts on commercialization focusing on cold atoms and quantum secure equipment/software as well as supporting industrialization and mass production through the local high-tech manufacturing and integrated photonics ecosystems. Leiden has a focus on theory and has several interesting quantum sensing startups. In Twente the focus lies on photonic quantum computing with a world-leading startup. In Amsterdam a more software and algorithm focus has generated a growing series of startups. Each region is therefore significantly different than the others, utilizing different technologies and strategies for the development and eventual commercialization of quantum technologies.

Significant support is offered from the Dutch ecosystem through education to engineering new quantum technologies: The Quantum Delta action lines support talent and learning centers in each hub across the Netherlands (in AL3), which utilize hands-on experimental education to educate the next generation of quantum researchers and to educate existing engineers that find themselves in a quantum context, working for a quantum company or their supply chain. This is increasingly relevant due to a new activity (in AL2): The quantum manufacturing alliance aims to connect the High-Tech Systems, Micro, Nano and photonic ecosystems to develop equipment and components for the quantum industry. Additional educational activity is needed to educate these companies to the subtleties of quantum technology.

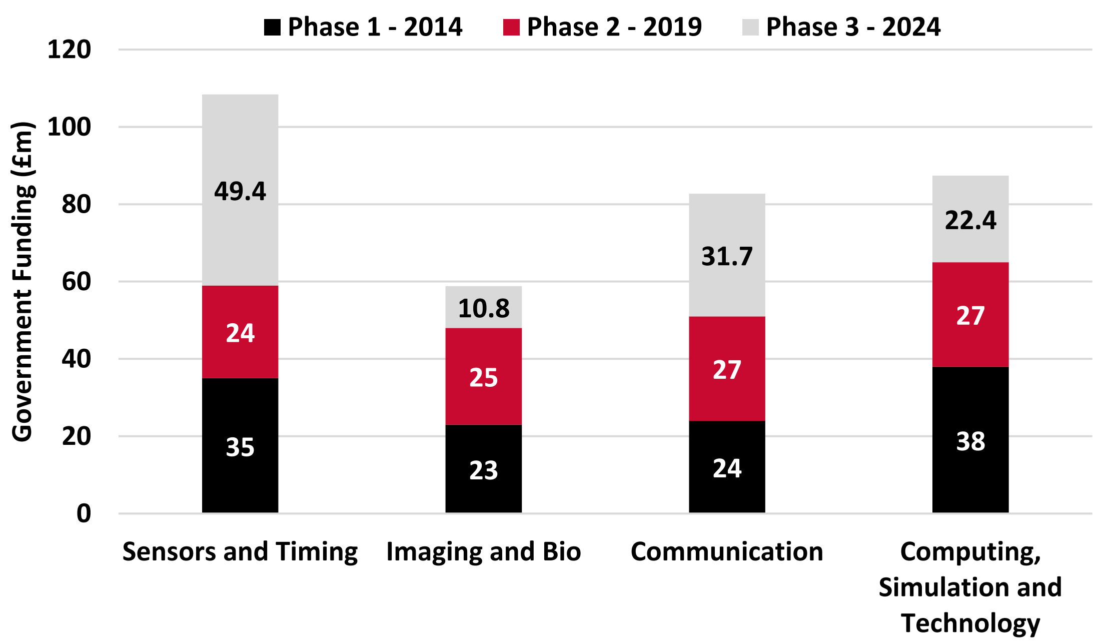
The quantum landscape in the United Kingdom

In 2023 the UK announced its updated National Quantum Strategy, that looks to build on the over £1bn investment it has made into Quantum Technology since 2014 (Department for Science, Innovation & Technology, 2023). Highlighted as an area of key and strategic importance to the UK economy, Quantum Technologies has a great disruptive potential for the economy of the future. It is strongly recognised as an enabler for vast economic opportunities, jobs creation and bringing key differentiating factors into the industries of the future. Development of new hardware and technology is widely recognised as difficult and long-term and hence the UK committed a further £2.5bn to support a confluence of Industry, Academia and Government to create a sustainable and growing quantum ecosystem. At this date of this publication, only a fraction (approximately a fifth) has been deployed or committed to date. The strategy outlines 4 key goals that builds on the world leading expertise and reputation in science and commerce in the areas of; technology leadership, high tech supply chain, quantum utilisation and regulatory framework.

Table 1, Targets for the United Kingdom National Quantum Strategy to reach in priority.

Priority Areas	2033 Target
Technology Leadership	• Maintain top 3 position in quality and impact of quantum science, • Train +1000 postgraduate researchers • Bilateral agreements with 5 further leading quantum nations
High Tech Supply Chain	• Obtain a 15% share of global private equity in quantum technology companies • Obtain a 15% of global quantum technology market
Quantum Utilisation	• All key sector business be quantum aware • 75% of key businesses have taken steps to implement quantum technology
Regulatory Framework	• Be a global leader in establishing global standards for quantum technology

These targets are confidently achievable by the UK as it was one of the first countries in the world to implement a dedicated and impactful national quantum technology programme. As a result of this early action more than 10 years ago, the UK has a thriving ecosystem that today already has the second largest number of quantum companies in the world, a complete coverage of expertise in quantum technology areas, world class testing capabilities and key user sector strength only second the United States. To date, the government via Innovate UK has funded £227m over 189 projects involving 182 companies for commercialising quantum challenges alone and these companies have raised £610m in private investments (Innovate UK, 2024). This industry has also been supported by a series of national quantum technology hubs to the tune of £343m since 2014 (table of funding in appendix) that cover the areas of:



With phase 2 of the existing quantum technology hubs having come to a close in 2024, a new portfolio of 5 hubs and centres have taken with 5 years £106m of funded programs and £54m from industrial contributions. The 5 hubs selected now are:

- The UK Quantum Biomedical Sensing Research Hub (Q-BIOMED)
  Led by: Professor Rachel McKendry, UCL and Professor Mete Atatüre, University of Cambridge

- UK Quantum Technology Hub in Sensing, Imaging and Timing (QuSIT)
  Led by: Professor Michael Holynski, University of Birmingham

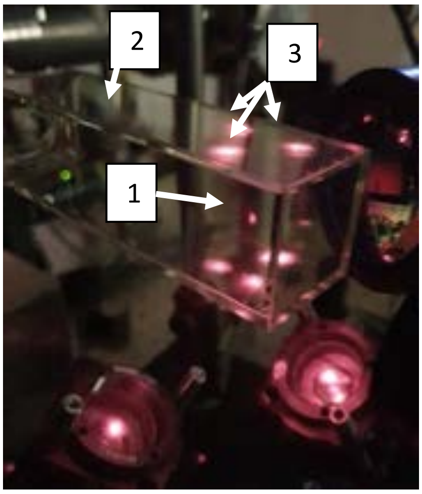
- Integrated Quantum Networks (IQN) Quantum Technology Research Hub
  Led by: Professor Gerald Buller, Heriot-Watt University

- QCI3: Hub for Quantum Computing via Integrated and Interconnected Implementations
  Led by: Professor Dominic O'Brien, University of Oxford

- The UK Hub for Quantum Enabled Position, Navigation and Timing (QEPNT)
  Led by: Professor Douglas Paul, University of Glasgow

These hubs will be applications-focussed quantum technology research as the developments in the UK has now considered to have matured sufficient to leave the laboratory. The UK is in a fortunate position with a dynamic ecosystem with companies operating at all levels from start-up to established primes as well as exploring all current areas of quantum, from single photon to ion based to cold atoms. A full consideration of this would be beyond the scope of the whitepaper and thus, the following will concentrate of the area of cold atoms based quantum technology.

Cold atom technology



The technology advocated by the Technical University of Eindhoven and Aquark Technologies has some distinct advantages over other methods for creating quantum systems. It works by trapping atoms (1) in a vacuum (2) by using light (3) and typically other electromagnetic fields. Traditionally this is done by capturing a cloud of atoms using an MOT (magneto-optical trap, frequency stabilised lasers in a quadruple magnetic field). Aquark has a proprietary trap method (pictured left), which doesn't require such a magnetic field, referred to as a Supermolasses trap and is therefore simpler, smaller and more durable. In the quantum technology fields, cold atoms occupy a unique position in that they are able to address all of the 3 pillars of development, computing, sensing and communication.

Quantum computers with cold atoms can be created from laser cooled atom clouds by using optical tweezers to capture individual atoms, which can then be used for quantum computing by manipulating them with several other lasers.

Atoms are all identical, which means that there are no manufacturing challenges in creating perfectly identical qubits. This decreases manufacturing development costs as well as allowing the build of useful quantum systems with (customized) commercially available components.

This method has tremendous advantages in scaling as it does not required the immediate extremely high investment costs that wafer manufacturing lines require. Developing integrated circuits is also very much an iterative process, that must be largely repeated when new materials are used. This slows down development and keeps the yield of effective qubits low as has been seen: Some superconducting qubit chips have hundreds of qubits, but only a small fraction are usable for quantum computing. Miniaturization and wafer manufacturing for scaling will still accelerate cold atom quantum computers in mid to long term through integrated photonics. This will enable scalable manufacturing, but after quantum advantage and effective computing use cases will already have been established. Lastly, cold atoms have the advantage of not needing cryogenic cooling. An effective quantum sensor or quantum computer based on cold atoms can cost as little as just the cryogenic system around other quantum technologies. Companies that work on this globally are: Atom Computing (US), Atom Quantum Labs(US), Infleqtion (previously Coldquanta) (US), Pasqal (FR), PlanQC (DE) and QUEra (US).

As quantum computing grows in power, it on one hands opens new opportunities in areas such as quantum memories and repeaters, while on the other it also creates concerns over potential threats such as the ability of existing encryption methods to withstand decryption by a quantum computer.

Quantum Communication looks to address the exchange of information using quantum methods. This can be "quantum internet", the exchange of qubits between quantum computers or “Quantum Key Distribution (QKD) the exchange of cryptography keys over a quantum channel. QKD encoded information fundamentally cannot be intercepted without notice, enabling security in a world where quantum computers might endanger information security. It is typically used in combination with post-quantum encryption algorithms. To enable the exchange of qubits over longer distances, a so-called quantum repeater is needed. A quantum repeater consists of quantum memory that stores the qubit and a transceiver. The repeater can then forward the qubit from node to node over fibre optic networks until it reaches the quantum computer on the other side for shared calculation.

Some types of QKD, but not all, use qubit exchange, which has the advantage that with a quantum repeater no special requirements are needed on the node. It does not see the data, so an attack on the node will not endanger information security.

It is, however, the view of the authors that greater technical challenges exist for qubit exchange than only those solved by a cold matter memory.

These issues include transmission distance limitations for qubit exchange since the data is encoded in single photons, and integration questions into traditional telecommunication. Typical transceivers have more or less the size and shape of a USB stick, and miniaturization to that point is far away for qubit exchange. The authors view this topic should therefore be revisited once greater progress has been made (at least 2-5 years in the future).

This is a topic for some commercial companies despite this challenges: WeLinkQ(FR) is a company utilizing cold atoms for this application. Hot vapour technology, which utilizes very similar principles, and requires a similar skillset to develop, is used by a variety of companies to develop quantum repeaters such as Qunnect Inc(US).

Quantum Sensors represent the most readily available and established market compared to computing and networking. Contesting with well-established technologies that have been pushing the boundaries of performance for decades, quantum looks to start where classical approaches peak performance. The two greatest challenges for quantum sensing is by far the environment in which sensing is required and the double edge sword that is high sensitivity. Often located outside the confines of controlled environments, sensors are required to work where data needs to be gathered or used and this mean instrumentation that keeps precision to a fraction of an atomic transition must be robust enough to allow the distinction between signals of interest and background noise. These challenges represent more engineering problems than limitations of science and will be solved by the application of robust development. The sensors produced are expected to provide new capabilities as well as direct improvements in:

- **Time keeping:** Greater resilience in time infrastructure such as GNSS, telecoms, financial transactions, electrical grids and navigation.
- **Inertial Guidance:** Reduced noise thereby limiting drift when navigating underground or in GNSS denied environments, using accelerometers, gyroscopes and clocks for dead-reckoning navigation.
- **Magnetometry:** More accurate data and mapping for brain imaging, material characterisation, process optimisation and multi-vector navigation.
- **Gravitometry:** Civil, geological and environmental infrastructures can be probed to get better insight into their condition. Monitoring of carbon captured, resource exploration, water and coastal monitoring.

It is worth noting that in quantum sensor, cold atoms are not the only platform available with devices based on trapped ions, trapped lattices, quantum dots, nitrogen vacancies or single photons also competing. Each are worthy of consideration, offering a different set of opportunities and challenges, but relative to cold matter, it is the universality of cold matter application and consistent high performance across them that are the key differentiating features. Companies that work on cold atom sensing and timing is: AOSense (US), Aquark Technologies (UK), Delta G (UK), Exail (FR), Infleqtion/Coldquanta (US), M Squared (UK), Spectra Dynamics (US), Teledyne (US) and Vector Atomics (US).

Accessibility to quantum technology has improved considerably in recent years, but it remains a challenge for all its use cases as hardware is often large, heavy, expensive and typically custom made. This slows progress and the development of impactful uses as not only is usage limited to experts in the technology, but also limits the development of a workforce surrounding it due to limited exposure. To address this, technology needs to be developed with a primary focus on the cost and ease of use instead of pushing for excess performance. By building robust hardware that researchers, engineers and students can rely upon, not only will quantum utilisation increase, but the gradual up-skilling of the workforce towards a quantum-enabled economy begin to be prepared.

Both the Netherlands and United Kingdom recognises the importance of quantum technology for the economy and the need for increasing the talent pipeline within their national strategies. The lack of talent in quantum is although, no means unique as the Science, Technology, Engineering and Mathematics sector has been lacking for several years with the UK alone recognising a shortage of 173,000 STEM majors estimated to cost the economy £1.5bn a year (IET, 2022), while in the Netherlands, 80% of technical organizations are expecting shortages in personnel (Engineers Online, 1999), with over 100.000 open vacancies in technology and ICT in 2023 leading to governmental action plans to increase education (Rijksoverheid, 2023). This means that a threefold problem exists with addressing the quantum talent pipeline:

- Challenges around approaching quantum without a STEM degree due to its high level of technical complexity
- high levels of competition within STEM degree holders from competing non quantum industries.
- Nascency of technology with limited time for knowledge to make it to the non-quantum use and its addressing affordability

Educational Initiatives and Workforce Development

The activities in the Netherlands and United Kingdom are largely centred around the national program for quantum technologies. One of the core components of the Dutch national program is the 3rd action line, which is dedicated to human capital. This action results in the activities on quantum education in the Netherlands being coordinated to synergise the different regions and connect with a variety of education levels and outreach at all age groups, from young children through students and even re-educating existing engineers.

In the United Kingdom, the training of human capital is addressed by a mixture of the Quantum Hubs (+£100m), industry partners like QURECA and Centres of Doctoral Training in Quantum (£14m) spread out all across the UK with some areas of overlap. This will primarily focus PhD level courses and research although dedicated quantum masters are also being setup. Little to no direct training occurs at undergraduate level or below.

In the Netherlands, efforts are to set up quantum dedicated masters in a coordinate way across universities with each having a different focus. Quantum information science and technology master are in the University of Delft and Leiden, a scientific master in quantum computing at Amsterdam and the University of Eindhoven has a master certificate program in quantum technology as an engineering discipline.

Besides the education of new masters/PhD level scientists in quantum technologies, a viable industry requires that other engineering is present and has the knowledge to work with quantum systems. Re-educating engineers in fields such as electronics, mechanics and software is therefore a key activity within the Dutch Quantum Delta program. This is implemented through a series of Training and Learning Centres (TLC's). The TLC's offer courses, which are partially implemented through challenge-based learning labs (CBL's) with a lot of hands-on quantum training. CBL's are also being implemented for Master and Bachelor quantum education.

From the University of Eindhoven, a lot of exchange with other universities is also happening, exchanging PhD's and master students.

For each of these educational activities it's important that the student can use educational grade equipment. A quantum lab setup is easily several hundred thousand if not millions of Euro/Pounds worth in value and requires a lot of finesse to use. The educational activities will therefore acquire their own equipment, with important requirements on cost, very clear and easy to access limited capabilities and a reasonable lifetime even when (mis)handled by many users.

Opportunities

Worldwide billions of investment is happening in quantum technologies sector with activity in both industry and academic environments. With quantum equipment being generally expensive, a very significant amount of investment is made to enable quantum capabilities and upcoming commercial systems.

In 2023 private investment in companies has decreased somewhat compared to the previous year, but remains high and in particular in education growth has continued (Leprince-Ringuet, 2024). With existing investment being expended and commercial sales prepared for the next few years, moving to development of quantum systems that can be produced at scale and a very significant and robust worldwide quantum research community, the demand for capable quantum professionals and engineers will only increase for the foreseeable future.

This requires investments in education from national programs such as the UK and Dutch ones described here. Other countries in the EU also have some sort of stimulus programs, with Denmark (1Bn DKK/134 m€, (Denmark, 2023)), France (1.8Bn€, (Invest in France, 2023)), Germany (2.65Bn€, (The Quantum Insider, 2023) and Italy (1.6Bn€ for 7 key technologies including quantum, (Rossi, 2021)). The EU itself also has programs on quantum, this includes the EuroQCI secure quantum networking infrastructure and its transnational Central European Facility counterpart, as well as the quantum flagship program (1 Bn€, (Quantum Flagship, 2018)). Also needed to be mentioned here is the EuRyQa project (EuRyQa, 2022), which is a 5m€ European collaboration under horizon, which offers collaboration on cold atom technology for quantum computing.

These programs require a large group of highly educated people, so the opportunity to provide educational equipment for this industry is therefore already large and will expand with more commercialization. Arguably due to the development status of most current quantum technologies and consumer acceptance at time of writing the educational market is the most mature market currently in existence for quantum equipment[1].

We are identifying several markets in this field for quantum systems:

- Undergraduate and graduate studies
- Hardware for vocational training
- Quantum re-education and upskilling of existing engineers

These inexpensive systems can also have third party uses, such as for startups to perform experiments or demonstrate proof of principles. Ruggedized and simplified systems can also be adapted into components for higher end commercial systems.

The requirements on systems such as these are relatively simple:

- They need to demonstrate a specific quantum feature and be flexible enough to perform experiments around this principle. A few examples:
    - Noisy 1 or 2 qubit quantum computers, spin-qubit systems are currently available at this level for this use case.
    - Breadboard quantum key distribution or quantum internet setups

[1] An exception can be made for atomic clocks and certain quantum sensors, which have been in commercial sales for some time.

    - The topical miniaturized cold atom trapping and control system
- They are required to be small such that they can be stored away in a cupboard when not in use, to enable efficient use of scarce educational space and protect any sensitive components.
- They need to be inexpensive, at most in the several 10's of thousands of Euro/GBP.
- They need to be very robust as they need to able to withstand a large group of students, each of which has the potential to misuse the technology due to a lack of knowledge.

According to the latest McKinsey monitoring report on Quantum there is approximately 350,000 graduates in quantum technology and relevant fields per year (McKinsey, 2023). Training of the ones working with hardware is likely to be a fraction of this and take place in established physics departments around the world. Using the 1370 counted by The Times Higher Education as a baseline together with the assumption that only 1 in 3 departments will work directly with cold atoms and graduate 50, this leaves 22,600 people a year with needing access to such teaching equipment (Times Higher Education, 2024). Using the median salary of these quantum educated professionals at $80,000 a year (SPIE, 2023), this represents a societal economic value of $1.8bn. This leaves a market for this equipment in the hundreds of millions.

As a target of strategic importance to both the United Kingdom and Netherlands, the development of hardware for educating quantum engineers represents a prime opportunity for UK/NL collaboration. Offering a global market economic opportunity and addressing key priorities, such a collaboration would become a cornerstone of the growing global quantum ecosystem and leverages the best of world class expertise and reputation of both nations.

To enable such opportunities the UK and NL should consider supporting collaborative initiatives between the nations in a manner similar to those recently pursued with Canada and German as well as those between NL and DE/FR:

- Canada UK Commercialising Quantum Technology Programme: CR&D (Innovate Uk, 2022)
- UK - Germany Bilateral: Collaborative R&D Round 3 (Innovate UK, 2024)
- Trilateral program between NL and DE/FR for quantum technology (Quantum Delta, 2022)

Future Roadmap and Milestones

The memorandum of understanding signed between the UK and the Netherlands signed on the 7th November 2023 expressly anticipates and supports the creation of funded collaborations. Partaking in the trillion euro/pound economy that quantum technology is expected to become, drawing parallels with the semiconductor industry, will require not only bold initiatives, but also the traditional factors of production, land, labour and capital. The high cost in capital and specialised labour that quantum requires mean we are likely to see a coalescing of activity into single locations. With many places with sufficient land to carry out quantum activity and ease of moving capital in the modern world, the establishment of a skilled workforce will likely be the greatest factor in determining the epicentre of the growing quantum ecosystem.

The United Kingdom and Netherlands occupy a unique position in this regard with excellent access to the world's talent pool as well as world renown teaching, commerce and research facilities. Netherlands and in particular Eindhoven is host to one of the world's biggest technology companies, ASML and with that has established a strong local ecosystem for carrying out deep tech at scale that quantum companies looking to scale should look to utilise. The authors therefore strongly recommend that bilateral funding and knowledge exchange opportunities for Dutch and UK companies, academia and industry be created to enable more close collaboration together and leveraging of individual strength areas. These should be implement both at the level of the research funding bodies, but also at the level of the Dutch catalyst program and UK Quantum Hubs with focus to achieve specific goals relevant to both national programs. For example, from the CAT3 Sensing Catalyst Program paired to the Quantum Sensing Hub, aiming to extend capabilities developed in both. This would benefit both ecosystems at large as the best of both can be brought forward, activity coordinated and resources best allocated to enable exploitation sooner in rapidly developing globally competitive market.

For the development of hardware for educating quantum engineers, the authors propose a 3 stage process for closer UK/NL collaboration:

- **Stage 1 – Foundational capabilities, gaps analysis and solution building**. This would be a 12 month period of joint exploration of each sides capabilities, needs and demonstrations to gather feedback and validate strategies. TRL target 1-3.
- **Stage 2 – Creating disruptive capabilities and initial implementation**. This would be a follow-up period of 12-18 months dedicated to serious efforts in maturing concepts and ironing any technical creases so seamless adoption of the technology can be obtained. TRL target 4-7
- **Stage 3 – Rollout, growing consortiums and applications**. For projects with clear value add, economic sustainability and established growing demand, the early adopters may still struggle with accessing the technology due to upfront costs. TRL target 8-9.

Each stage would see a shift in funding support from solution provider to end users with stage 1 primarily focusing on the solution provider and stage 3 focusing on the end users.

In deploying such a program, hardware for educating quantum engineers could be developed with a shared risk and return between SMEs, Academia and Countries. Developing these inceptional capabilities, skilled talent and supply chain to support on global stage will be pivotal in bringing the epicentre of quantum development closer to both ecosystems and fulfilling the national quantum strategies.

Conclusion

The United Kingdom and Netherlands are both leading in the field of quantum technology with ambitious national strategies for quantum technology and a mutually beneficial opportunity exists for joint-collaboration and co-development. Deploying programs similar to those established by the UK and NL with Germany, France and Canada would create a foundation for immediate direct engagement with route to economic benefits in the hundreds of million euros in size. Development of projects such as hardware for educating quantum engineers will leverage UK expertise in building compact cold matter technology with NL expertise in challenged base learning, teaching and quantum education. Such a project would not be unique as many other similar opportunities could be established through the interface between the Dutch catalyst and UK Quantum Hub programs giving way to even greater economic development and delivery of national strategies.

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UK Quantum Hub Funding

The original 4 hubs have now concluded after 10 years and a new set of 5 hubs have been established in 2024. While not explicitly referred to as phase 3, the author's have adopted this terminology as the hubs builds on the previous learning and in some cases are superseeding previous hubs at the same institution.

Hub	Lead	Funding
UK National Quantum Technology Hub in Sensing (Imaging) and Timing	University of Birmingham	Total £91.5m Phase 1 £35,513,855 (EPSRC, 2014) Phase 2 £28,537,607 (EPSRC, 2019) Phase 3 27.5m (2024)
The UK Quantum Technology Hub in Quantum Imaging superseded by The UK Hub for Quantum Enabled Position, Navigation and Timing (QEPNT)	University of Glasgow	Total £69.9m Phase 1 £23,061,154 (EPSRC, 2014) Phase 2 £24,961,172 (EPSRC, 2019) Phase 3 £21.9m (2024)
The EPSRC Quantum Communications Hub	University of York	Total £51.4m Phase 1 £24,093,966 (EPSRC, 2014) Phase 2 £27,348,141 (EPSRC, 2019)
EPSRC Hub in Quantum Computing and Simulation Superseded by QCI3: Hub for Quantum Computing via Integrated and Interconnected Implementations	University of Oxford	Total £87.8m Phase 1 £38,029,961 (EPSRC, 2014) Phase 2 £27,338,781 (EPSRC, 2019) Phase 3 £22.4m (2024)
The UK Quantum Biomedical Sensing Research Hub (Q-BIOMED)	University of Cambridge	Total £10.8m Phase 3 £10.8m (2024)
Integrated Quantum Networks (IQN) Quantum Technology Research Hub	Heriott-Watt University	Total £31.7m Phase 3 £31.7m (2024)

Comparison of cold atoms to other technologies

Note: Information indicated here is illustrative. The take-away here is that each of these technology types has specific advantages, disadvantages and uses. We have specific expertise in cold atoms so information while focus on being objective is at risk of bias and knowledge on other qubits may be somewhat out of date.
The authors express no opinion on one qubit being better than any other, other than on our own type, cold atoms, which is obviously the best.

For more specific background information we recommend the excellent book of Olivier Ezratty, Understanding Quantum Technologies. The current version is the 7th edition and is available for free from https://www.oezratty.net/.

The core technology for most quantum technology is the qubit. Qubits are a 2 state system, where it is possible to create a superposition between these two states. Beyond this they need to be able to be maintained for a sufficient time, interacted between and read out. Fundamentally any 2 state system that complies with this can be used to create a quantum computer, which has led to a wide range of candidates.

For quantum sensing and networking other requirements are needed, such as interaction with light for communication and sensitivity to specific factors for sensing.

Roughly speaking qubits fall under three separate types: Integrated qubits, Photonic qubits and matter qubits, which includes trapped ions and neutral atoms. Below we will compare our neutral atom qubits with the other qubits.

Integrated qubits

The currently most common type of qubits are the integrated qubits (creating a qubit through a structure on a chip, just like a traditional chip). By far the most well-known at the moment is the superconducting qubit (Included in IBM quantum computers for example), with spin-qubits, spin-SiGe qubits and topological qubits with many variants also under development.

The famous pictures of a quantum computer looking like a chandelier comes from this type of qubit: This is the wiring coming in from the top, into the restricted space of a cryostat that maintains the low temperatures needed.

These technologies have obvious advantages in scalability for computing. Creating a wafer, then producing devices on it for computation is a scaling methodology that we have developed over the last 50 years. Issues in fidelity and manufacturing problems still have to be overcome. Limitations in device density per chip due to heat generation in very cold cryogenic requirements is another challenge.

Compared to neutral atom qubits, the core differences are in the interfaces. Since there is no material interface to the neutral atom qubits (they are held in space by lasers) there is less interaction damaging the quantum state and the temperature can be further reduced with laser cooling (mK to µK) which helps stabilize the quantum state further and ensures no cryostat is needed. Neutral atoms can be produced in unlimited numbers (if enough light beams are created) and are perfect qubits: each atom behaves exactly as its neighbour. While scaling limitations do exist (see below), much larger quantum computers are available currently with thousands of qubits per system versus several hundred integrated qubits per system.

For communication there is also an advantage to the neutral atom platform, and these are being developed as quantum memory (especially variations using atom cloud methods). The interface being optical makes interfacing with a fibre network significantly simpler as the quantum signal does not need to be converted from electronic to light. Significant work has however been done to convert quantum signals from integrated qubit systems like superconducting to allow for scaling.

In the sensing field, the technologies have different applications on what they measure. The lack of required cryogenics and ability to withstand vibration makes miniaturized sensing systems for neutral atoms very applicable in the field with commercial applications being developed for markets such as aerospace applications. Superconducting quantum sensors are also well established and used in scientific applications but remain high cost.

Photonics

Using the properties of light itself to create a qubit is a logical step. Light is by its nature polarized, which has multiple states, can be relatively easily put in a superposition and light interferes with other light, making interaction possible. Light is however also fleeting, since it is always moving at the speed of light. Integrated photonics methods to create quantum computers are relatively mature and are used for example in the LIGO detector that detected gravitational waves for the first time.

Photonic techniques are used in many of the other quantum methodologies to allow for scaling. This includes the neutral atoms, trapped ion and diamond NV-centers (see below) as well as to enable quantum communication between all other types of quantum computers.

Integrated photonic quantum systems are also the default technology to develop secure quantum communications systems (quantum key distribution).

Compared to neutral atom systems, the clear advantage is in the ability to create chips, which has similar advantages in leveraging production methods compared to the integrated qubits above. However this is somewhat limited due to macroscopic connections required for input output through fiber. This limits the amount of qubits that can be integrated on a single chip and so requires the use of many chips.

Unlike neutral atom quantum computers, it is not possible to store photons so tricks are required, such as backpropagating the quantum state through the system (keeping it in motion) and storing qubits for a short amount of time in very long optical fibers.

Atom based qubits

The third type of qubit are those that are using the properties of atoms themselves to create the qubit states.

the first two are the cold atom based quantum systems that this whitepaper is based on and trapped ions. These atoms/ions are isolated in a vacuum, kept in place using magnetic and optical methods and controlled using lasers or microwaves.

One other important type of qubit to be named is the color center qubit, where one atom in diamond is replaced (traditionally with a nitrogen atom called nitrogen vacancy or NV-center), but alternatives are now becoming popular).

This creates a qubit that has some similarities to the integrated qubits (as it's a manufactured diamond chip) but it mostly fits in this block, as the qubit is based around a single atom and is commonly controlled using light.

NVcenters have an obvious advantage for quantum communication. They are qubits in a wafer that allow for optical in and output, with much lower requirements for cryogenics compared to integrated qubits. For computing they are somewhat less developed compared to trapped ions and neutral atoms, with limitations in diamond wafer manufacturing and production, a lower fidelity and, and the development of integrated photonics interfaces another requirement to enable true scaling.

Of these three, trapped ions currently have the record for highest fidelity, but the gap is getting smaller. Neutral atoms are the most scaled quantum computing systems that currently exist, with over 1000 qubits per system now standard and increasing fast. Limitations in scaling occur in the amount of laser power required and splitting and individually controlling light beams to each atom, both of which have a potential solution in integrated photonics. Unique to neutral atoms is the ability to move atoms around, which allows any atom to interface with any other atom in the system. This reduces the amount of connections needed to be created but at the cost of speed, as this operation takes time.

In terms of sensors all three technologies have significant applications. Each technology has the capability of being miniaturized, no (or limited) requirements on cryogenics and many capabilities such as magnetometry, chemical sensing and RF analysis are distributed between the technologies, allowing each to operate in their own niche, while competing in others. Cold atoms in this space are unique due to their ability to be fundamental measurement standards and therefore self-calibrating. This enable measurements of not only the ultra precise level, but also in a large variety of metrics such as magnetic and electric fields as well as inertial forces.

HOW GENERATIVE AI IS REVOLUTIONISING THE COMMUNICATIONS INDUSTRY BY EMPOWERING EVERYONE

UP!
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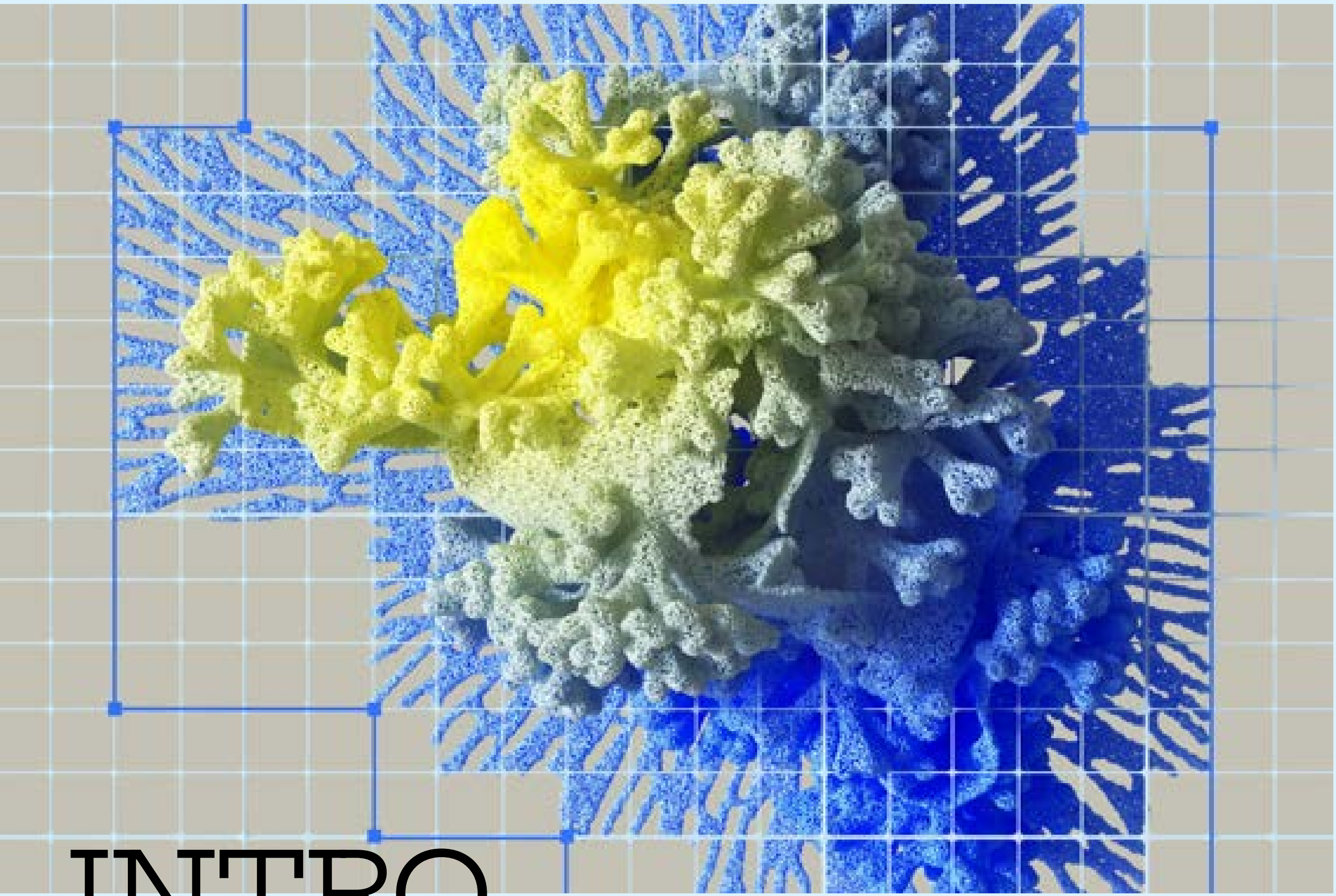


INTRO

GEN AI FOR ALL: A CASE FOR INNOVATION

In just two years, generative AI has redefined the boundaries of creativity and productivity. Nowhere is this -transformation more visible than in our own industry: communications. Tasks once considered uniquely human—crafting words, creating images, understanding data or critiquing strategies — can suddenly performed by AI, and quite often, even better. As our industry adapts to this seismic shift, we're faced with a profound question: How do we navigate a future where machines can do much of what we once considered our differentiating capability?

In this Whitepaper, we share our approach to driving innovation with generative AI. You will learn how introducing AI requires a fundamentally different strategy from previous technologies, requiring both top-down and bottom-up approaches, and you will find real world use cases of how to successfully integrate generative AI within organisations, including a comprehensive guide to a building a strategic framework.

CONTENTS

Special thanks to the Netherlands Innovation Network UK and the Embassy of the Kingdom of the Netherlands in London for their support in the production of this white paper as part of its programme to stimulate international cooperation for companies, research institutes and public authorities in the fields of innovation, technology and science.

Over the past year, ainigma and communications agency Grayling have worked on generative AI implementation projects with thousands of employees worldwide across Grayling's 30 global offices. We've trained everyone from management assistants to board leaders. The overall sentiment is paradoxical: excitement about AI's potential is tempered by significant apprehension. Now we have moved beyond the hype, the real question is: How do we move forward? What does it mean for me, for us, and for the world?

Studies consistently show that generative AI can enhance productivity by over 20% in the short term . In industries with narrow margins, such as ours, this could be transformative. For example, analysis suggests that writing jobs can see productivity enhancements of up to 32% . In London alone, hundreds of thousands of people work in communications, and the potential impact of generative AI is enormous. Just this week, the BBC reported that a tech company replaced a full team of 60 writers and editors with Gen AI within one year . "I more or less got automated out of a job", the head of that team said.

It's easy to say that humanity has always adapted to new technologies. People once feared the steam engine, Queen Elizabeth the First rejected the knitting machine, fearing the machine would lead to unemployment. In the communications industry, we've transitioned from using pens and faxes to BlackBerry and PowerPoint. However, acknowledging this historical adaptability doesn't negate the challenges of the current transformation. In some of the teams we worked with, over 40% of respondents expressed concerns about AI affecting their jobs.

A full analysis of the impact of generative AI would fill many books and cover various perspectives, including legal, philosophical, and economic viewpoints. Nor is this paper an introduction to generative AI, excellent resources like Ethan Mollick's Co-Intelligence are widely available (or simply ask ChatGPT for a short explanation in the tone of voice you like!). Instead, this paper focuses on the struggles organisations face in bringing generative AI to all their people and the potential consequences of failing to do so.

We cannot simply tell people that it will all be fine. Organisations will need to provide training and upskilling to help people adapt. The good news is that once people start using Generative AI, they often become excited. Our internal research shows that generative AI can enhance jobs by freeing up time for more interesting and productive tasks. We have seen that early adopters of Gen AI thrive in the workplace. They develop new service offerings and spend less time on tasks they previously found boring. Perhaps most importantly, you do not need a technical background to work with Generative AI. All you need to do is… communicate well with the AI, and that's exactly what people in our industry excel at.

Recent findings from larger research papers confirm the early indications we've seen in our teams. A study by Microsoft and LinkedIn found that 91% of employees who are 'power users' of generative AI enjoy their work more, and 83% feel more creative. This tells us one thing: we need to bring Gen AI to everyone. While some individuals benefit significantly from AI, most others (68%) are not using it frequently and have not integrated it into their workflows. Even more concerning, 36% of PR professionals had never used generative AI as of early 2024. Organisations must act to prevent a new digital divide.

This divide indicates a broader organisational challenge. The real transformation should occur across the entire organisation, not in silos. There's a clear gap between the exciting potential of generative AI and the reality of making it work. The communications industry is lucky to attract young, curious employees who have already experimented with Gen AI at home or school. These individuals can help shape the future of our industry. But for this to happen, organisations must be open to change and encourage innovation at every level. This is both our challenge and our opportunity.

[1] https://www.hbs.edu/ris/Publication%20Files/24-013_d9b45b68-9e74-42d6-a1c6-c72fb70c7282.pdf
[2] https://www.reuters.com/legal/transactional/ai-improves-legal-writing-speed-not-quality-study-2023-11-08/
[3] https://www.bbc.com/future/article/20240612-the-people-making-ai-sound-more-human
4 Use the prompt: "Explain how Generative AI works in 80 words in the style of Shakespearean tragedy"
[5] https://www.cision.com/resources/articles/how-prevalent-generative-ai-in-pr-comms/
[6] https://crenshawcomm.com/blogs/the-state-of-ai-in-pr-takeaways-from-muck-racks-2024-report/

01

THE WORLD IS DYNAMIC, NOT STATIC

Zooming in on our industry, the potential power of gen AI to transform jobs cannot be understated. From meeting notes to brainstorming concepts, from analysing vast amounts of data to image generation and campaign imagination, generative AI can save time. Lots of time. 30%? 50%? Brace yourself: Sam Altman, CEO of OpenAI, has stated that generative AI will be able to do 95% of the work marketers use agencies, strategists, and creative professionals for today.

We believe this widely shared quote misses the mark. It might be correct from a static perspective on the output of our industry today, but not on the possibilities generative AI can create. Let's explore two perspectives on its impact: static, focused on automation and dynamic, focused on augmentation.

From a static perspective, the goal is to automate the production of communication materials we see today—the same LinkedIn posts, press releases, and websites. In this view, machines would replace human labour, leading to massive job cuts as routine tasks are automated. Communication agencies and departments would face pressure to cut costs, potentially reducing spending by 30-70%. Organisations that focus on automation might choose to invest heavily in technology that can replace people, resulting in a world where output remains the same, but machines perform the work humans once did.
This approach, however, overlooks the true potential of AI to transform and elevate human work. Consider how music videos today are far more sophisticated than those from 20 years ago. The quality of an average PowerPoint presentation (yeah!) has dramatically evolved, and the design of local restaurant menus are artworks compared to just a couple of years ago. All because more people got access to more powerful creative tools.

A dynamic perspective recognises that technology has always been used to enhance creativity and create more personalised, impactful tools. When the French painter Paul Delaroche saw the first camera around 1838 he said: "From today, painting is dead". Little did he know. The introduction of smartphone cameras has not reduced, but in fact, released the amount of creative content in the world. It enables artists to create music videos independently and politicians to directly address audiences.

The dynamic perspective sees AI not as automating human labour, but augmenting human capability. Generative AI will empower all of us to produce more content at a lower cost, significantly improving the quality and targeting of information. And with this shift, market needs will change too: customers will get accustomed to gen AI enhanced communications, people will expect that communication is always targeted to their personal preferences, and we all will probably engage with multiple different AI-avatars on a daily basis. Imagine personalised health communications tailored to individual needs, content designed for people with literacy challenges, or multilingual messaging that reaches diverse audiences effectively.

We believe that rather than replacing jobs, a different change will happen: Expectations for communication departments, agencies, and experts will shift significantly. For communication professionals, embracing generative AI means fully integrating these new tools into their workflows. Just as PR professionals now understand the dynamics of social media around an IPO, organisations must adapt to generative AI. This involves fostering an environment where innovation can thrive at every level, ensuring that AI enhances rather than replaces human creativity.

CHALLENGES OF ADOPTION

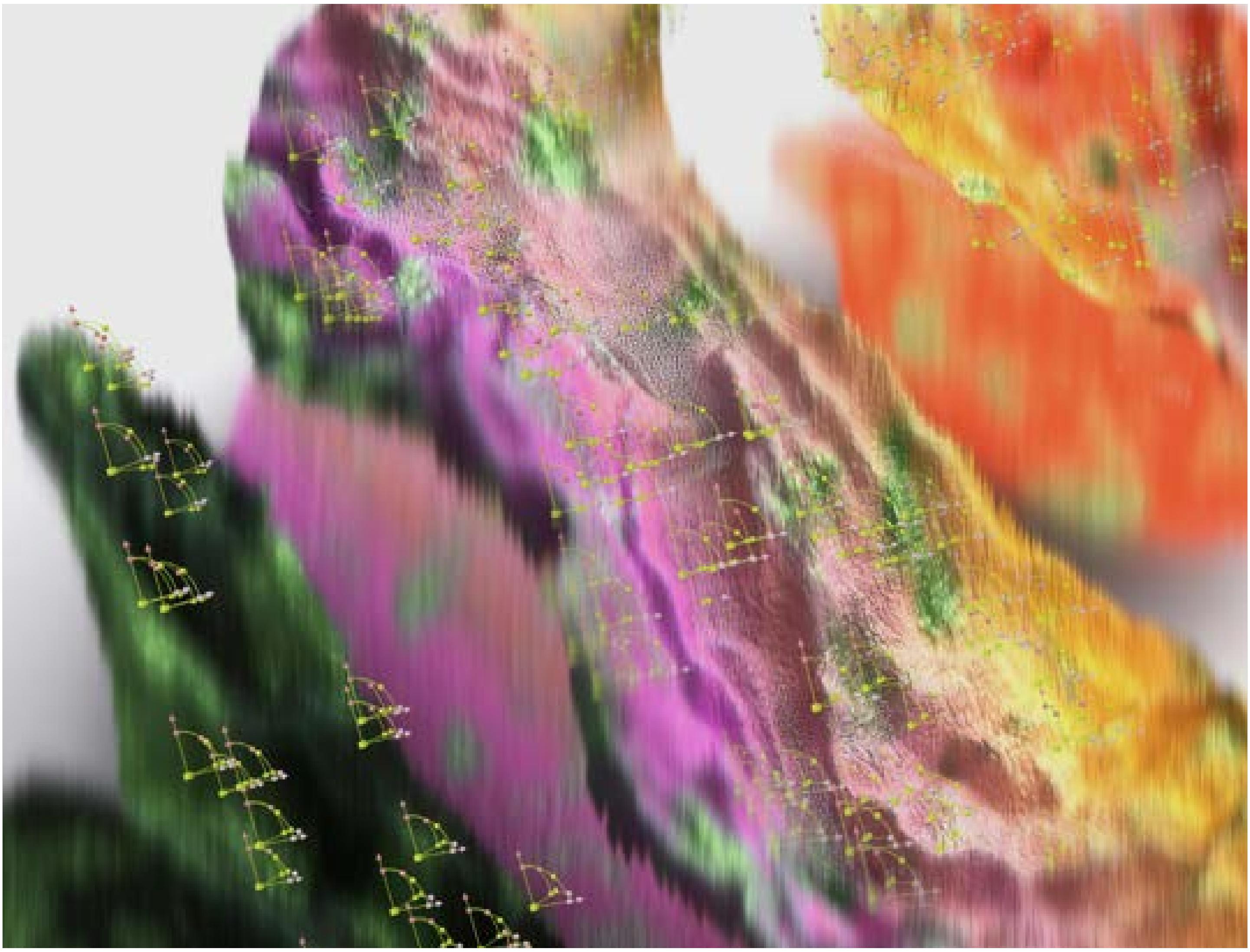
In this paper, we present our approach to driving change and innovation with generative AI. The speed at which this technology is being adopted is unprecedented. Unlike the gradual uptake of social media, which took 24 months to reach widespread use, generative AI reached 100 million users in just two months. This rapid adoption has tangible financial implications: the Financial Times reported a that "within a few months of the launch of ChatGPT, copywriters and graphic designers on major online freelancing platforms saw a significant drop in the number of jobs they got, and even steeper declines in earnings." As the quality and ease of use of Gen AI continues to evolve and its adoption rates climb, these trends are likely to persist, highlighting the urgent need for organisations to develop comprehensive strategies for integrating AI.

Additionally, the pressure to adapt to generative AI comes from within organisations themselves. You don't need to be an expert to use generative AI effectively, and often, junior staff members are quicker to adopt these tools than their senior counterparts. In many cases, these employees are using AI tools independently, sometimes even without explicit permission, to enhance their productivity and creativity. This grassroots adoption creates a dynamic environment where innovation is continuous, new business models emerge, and traditional work margins are increasingly challenged.

COMPREHENSIVE CHANGE MANAGEMENT

Picture a scenario where an internal communications team, empowered by AI, creates personalised messages that resonate deeply with every employee. Achieving this vision requires a comprehensive approach to change management. The cost of AI tools is relatively low, but the productivity gains—freeing up 2-4 hours per week—are invaluable. These gains should be reinvested in training and upskilling, ensuring that all employees can harness AI's potential, just as Publicis is doing with its €300 million gen AI investment[7].

Realising this potential requires a holistic strategy that blends rapid adaptation, strategic tool utilisation, and comprehensive change management. This approach differs significantly from the disjointed efforts seen today. By adopting a holistic strategy, organisations can ensure that AI not only enhances productivity but also fosters a culture of creativity and innovation. This will enable companies to thrive in an AI-driven future, where generative ai unleashes human creativity.



[7] https://www.reuters.com/technology/publicis-invest-300-mln-euros-ai-plan-over-next-three-years-2024-01-25/

02

DIFFERENT (AND WRONG) ORGANISATIONAL RESPONSES TO GENERATIVE AI

In the era of generative AI, organisations often adopt two prevalent but flawed approaches: the IT-driven approach and the innovation-department-led approach. While these methods may seem logical, they fall short in fully harnessing the transformative potential of generative AI.

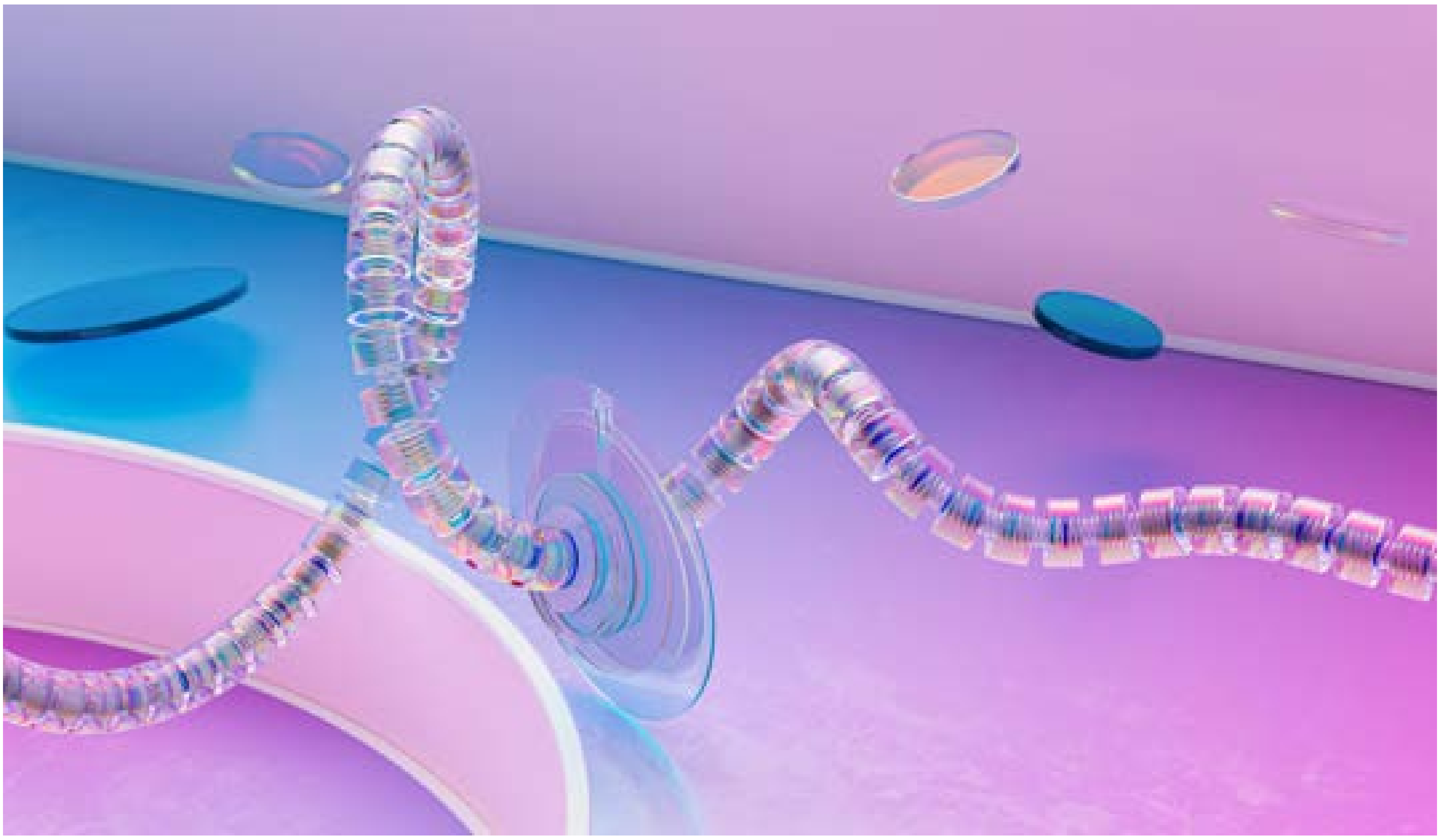
IT-DRIVEN APPROACH

Many organisations view generative AI as a purely technological development that should be managed by the IT department. Their primary focus is on building tools to enhance productivity and automate processes, often with the goal of cutting costs. For example, the software platform Typetone offers an AI tool called Social Media Sarah. Their claim: "Hire an experienced content marketeer for less than the price of an intern!" While on first glance this may seem appealing from a cost-saving perspective, it overlooks the significant impact such messaging can have on employees and even wider society. Imagine your boss introducing a new tool that openly discusses replacing people—it's demoralising and will only create anxiety.
But also on a more fundamental level, the focus on tools misses the point. Creative work is not about fixed processes but about the value created by humans. It's challenging for an external IT-consultants to develop specific tools that meet the nuanced needs of various business functions, without having an understanding of the jobs done. More importantly: as we have just seen, this IT-driven viewpoint looks at automating the current work, rather then enabling possibilities of the future. However, market dynamics point in a technological way: venture capital fuels the attention for SAAS solutions and companies eager to showcase their technological investments often pour resources into proprietary tools and software.

However, with the rapid advancements in AI technology, these supposed cutting-edge solutions may quickly become outdated. 'Multi-modal' Gen AI, meaning AI applications that can seamlessly deal with vision, voice and text at the same time, is coming fast, unlocking many new innovative possibilities. Imagine investing millions in a new software solution today, only for it to be rendered obsolete by the next iteration of ChatGPT.

The COO of OpenAI recently predicted that in a year, we would view the current quality of generative AI as laughably bad[8]. Investing heavily in a tech solution that might soon become obsolete is a significant risk. Additionally, rolling out a stable and effective generative AI system across an organisation requires substantial investment, posing a barrier to companies hesitant to commit due to the associated costs and risks.

The result is that the IT department focuses on transformational automation projects that promise significant returns – where Gen AI definitely could add value – but overlooks the value Generative AI is already bringing to the workplace today. While IT departments play a crucial role in implementing generative AI for significant transformations, relying solely on them limits the potential benefits.



[8] https://www.businessinsider.com/openai-exec-says-ai-will-be-laughably-bad-in-year-2024-5

SILO APPROACH

Some organisations opt to establish isolated silos or labs dedicated to generative AI, aiming to develop new products or services. They bring in a bunch of experts and tell this group to 'innovate with AI'. While this approach can foster rapid innovation within the silo, it often fails to integrate AI effectively throughout the organisation, leading to fragmented and limited impacts. Internal task forces, made up of early AI adopters, are another variant of this approach. These groups are typically enthusiastic but lack the diversity and authority needed for significant change.

The mistake this approach results is that the true transformative potential of generative AI lies in its application at the task level, and those tasks are hard to see from afar. For instance, one of the authors of this white paper is a global chief innovation officer. How could I fully understand how generative AI can support our public affairs teams without direct insight into their daily work?

Confining AI innovation to a single department misses the daily innovations employees could uncover. Thousands of tasks are completed daily, and over 60% of knowledge workers are already exploring tools like ChatGPT to improve their work. Isolated innovation hubs or task forces will never capture this widespread creativity.

It's no surprise that forward-thinking companies like Moderna have adopted a bottom-up approach[9]. Their CEO's endorsement of widespread Gen AI experimentation has resulted in over 750 internal GPT bots assisting with various tasks, showcasing the significant benefits of a top-down commitment to AI integration.

CONCLUSION

Both the IT-driven and silo approach to generative AI adoption have significant limitations. They either overlook the human element or fail to integrate AI across the organisation effectively. To truly harness the power of generative AI, organisations must move beyond these flawed strategies and embrace a more holistic, inclusive approach. This sets the stage for the next chapter, where we will explore the importance of bottom-up innovation in the era of generative AI.

[9] https://openai.com/index/moderna/

03

BOTTOM-UP INNOVATION

In the era of generative AI, the importance of bottom-up innovation cannot be overstated. Across the world, we see many new start-ups by individuals who began exploring AI tools out of curiosity and make significant impact with very small teams. For example, Dutch 'solopreneur' Pieter Levels built PhotoAi.com all by himself, while the team that built the highly successful online image generation tool Midjourney consisted of just 11 people, according to reports in October 2023[10]. These successes are not because these individuals suddenly became much smarter, but because generative AI tools have empowered them to achieve more than ever before.

[10] https://research.contrary.com/reports/midjourney

When you give creative, imaginative people access to generative AI tools, you unlock their boundless potential. The process is very similar to how social media unlocked many people's creativity: by providing individuals with accessible creative tools in a simple app like Instagram or Tiktok, people all over the globe discovered different ways to unleash their creativity – the tools unlocked a creative potential that had always been there, but just never saw the light. Just months after releasing the AI-music generation tool Suno, already over 10 million users started to create music.[11]

What social media platforms did for content creators, generative AI is unlocking in all of us, across all professions: it's a technology that makes us much more powerful. But that can only happen if we can all use it in our organisations on a daily basis, without thinking: *Gen AI is not for me, it's too complex or too costly.* Because that's not the case:

❶ AI IS INTUITIVE AND ACCESSIBLE

Using AI doesn't require deep technical know-how (really!) but rather curiosity, creativity, and a willingness to experiment. AI tools can with a couple of very simple prompts generate ideas, understand data and give sophisticated feedback. Already after a couple of tries, all knowledge workers can start reaping the benefits of the tool. For instance, a marketer can ask ChatGPT to review a social media calendar, a designer could use ChatGPT to demystify a complex brief, a researcher can simplify their often too complex wordings into simple language, and a teacher can, in the space of a few minutes, create different math assignments depending on the results of a football match the day before. And although ChatGPT is our current go-to, soon we will see the AI applications being even more integrated into our day-to-day software platforms.

❷ AN ENDLESS AND UNKNOWN NUMBER OF USE CASES

AI has vast applications across an organisation, and siloing its use limits its potential. Ethan Mollick states that Gen AI operates on a "jagged frontier",[12] where its capabilities vary widely across different tasks. Some tasks, like idea generation, are surprisingly easy for AI, while others, such as basic math, may present unexpected challenges. This uneven landscape means that encouraging widespread experimentation and use of AI within an organisation can uncover new, valuable applications that might otherwise remain hidden. Bottom-up AI adoption enables employees to use AI tools to solve problems, create value, and generate impact in their domains and functions.

❸ LOW COST OF EXPERIMENTATION

Finally: the cost of experimenting with AI is incredibly low. All you need is a subscription to platforms like Microsoft Copilot, ChatGPT Enterprise, or Google Gemini allows safe and accessible experimentation, providing employees with the best tools available for €25 a month.

Imagine a designer in your team who excels at design but struggles with communication. Perhaps they don't speak the language well or lack the skills to write a proper briefing email. With the help of a generative AI bot connected to their email/chat system, this designer could communicate perfectly, streamlining team interactions and potentially working remotely from any part of the world.

[11] https://suno.com/blog/fundraising-announcement-may-2024

[12] https://www.oneusefulthing.org/p/centaurs-and-cyborgs-on-the-jagged

Organisations are full of employees who perform these kinds of various tasks that can be improved on a daily level. These employees are best positioned to discover how generative AI can support and innovate their work. Encouraging and empowering them to engage with AI technologies can transform how organisations operate and thrive.

To truly leverage the power of bottom-up innovation, organisations should identify and harness those within the business who already have an affinity and understanding of AI. These individuals can be pivotal as AI champions or advocates, driving adoption and inspiring their peers. PR agencies, in particular, have a demographic that makes them uniquely positioned to adapt to and adopt change. With a substantial pool of younger employees who are already familiar with AI from their studies, the focus should not just be on changing behaviour but on harnessing existing behaviour.

Gary Lloyd, in his book "Gardeners Not Mechanics: How to Cultivate Change," emphasises treating organisations as ecosystems rather than machines. Drawing on key management theories such as systems thinking, behavioural science, and design thinking, Lloyd advocates for recognising the unpredictability, interdependence, and limits of control inherent in organisational ecosystems. He argues that sustainable change is more achievable when organisations foster a culture of experimentation and support bottom-up innovation. Lloyd likens this to a gardener's approach, where small, iterative changes are cultivated and adapted based on the environment's feedback, rather than imposing rigid, pre-determined plans.

A look at future of AI-powered roles can be seen at the Dutch neo-bank Bunq. They have introduced new roles across the business called process owners. Employees who once performed tasks that are now handled by Generative AI, are responsible for the quality and growth of those bots. They are collaborating with AI to create an even greater impact. AI hasn't replaced them; it has enabled them to engage in more powerful and valuable work.

By fostering a culture of bottom-up innovation, organisations can fully leverage the capabilities of generative AI, driving significant value and transformative change.

04

TOP DOWN EMPOWERMENT OF INNOVATION

But how simple bottom-up innovation sounds, it's much harder to bring it into reality. A lot of companies who bought subscriptions to Microsoft Copilot, see very little adoption from their users. So how come that even when you have the full IT-infrastructure is ready and the promises of these tools are so big, change is not happening? Well, It's change management.

The challenges of effective adoption often stem from a lack of skills, resources, leadership support, or a clear vision. AI's unique nature demands a dual approach: strategic direction and support from leadership combined with grassroots innovation and experimentation from employees.

Leadership must set the ambition, legitimise AI use, and establish parameters for ethical and effective application. Simultaneously, empowering employees to explore AI's potential and integrate it into their daily tasks ensures widespread, meaningful adoption.

This integrated approach maximises AI's impact, fostering an environment where both top-down guidance and bottom-up innovation drive organisational success.

[10] https://research.contrary.com/reports/midjourney

❶ SET THE AMBITION

Leadership must clearly and vocally set the organisation's ambition with AI. This is an opportunity to excite and motivate staff, acknowledge their role in driving change and innovation, present the organisation as dynamic and progressive, and emphasise the role of humans in the loop.

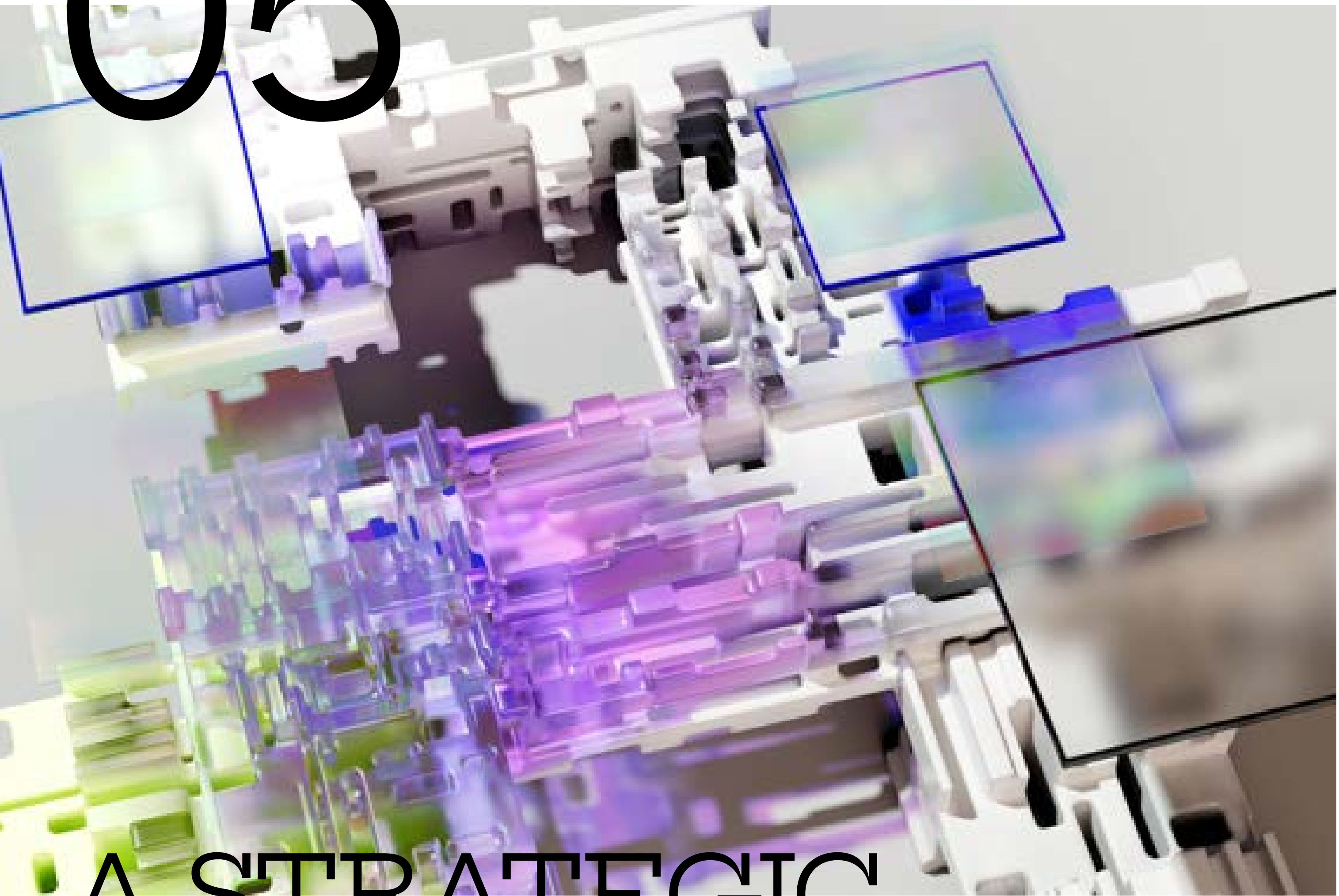
❷ LEGITIMISE ITS USE

Leadership needs to legitimise the use of AI across the organisation. Without this support, employees might explore AI in unofficial and fragmented ways, stifling overall innovation. Leadership must decide which AI platforms to invest in and ensure they are available to relevant employees. However, technology alone is not enough; it's essential that employees are trained to use these tools effectively.

❸ ESTABLISH THE PARAMETERS

Successful innovation comes from giving employees the freedom to explore within set parameters. These parameters must reflect the organisation's IT protocols and legal and ethical guardrails. Given AI's nascent state, many organisations will need to update existing guardrails or develop new ones, such as adding AI usage policies to existing client and customer contracts or establishing the ethical framework against which the organisation holds itself to account

05

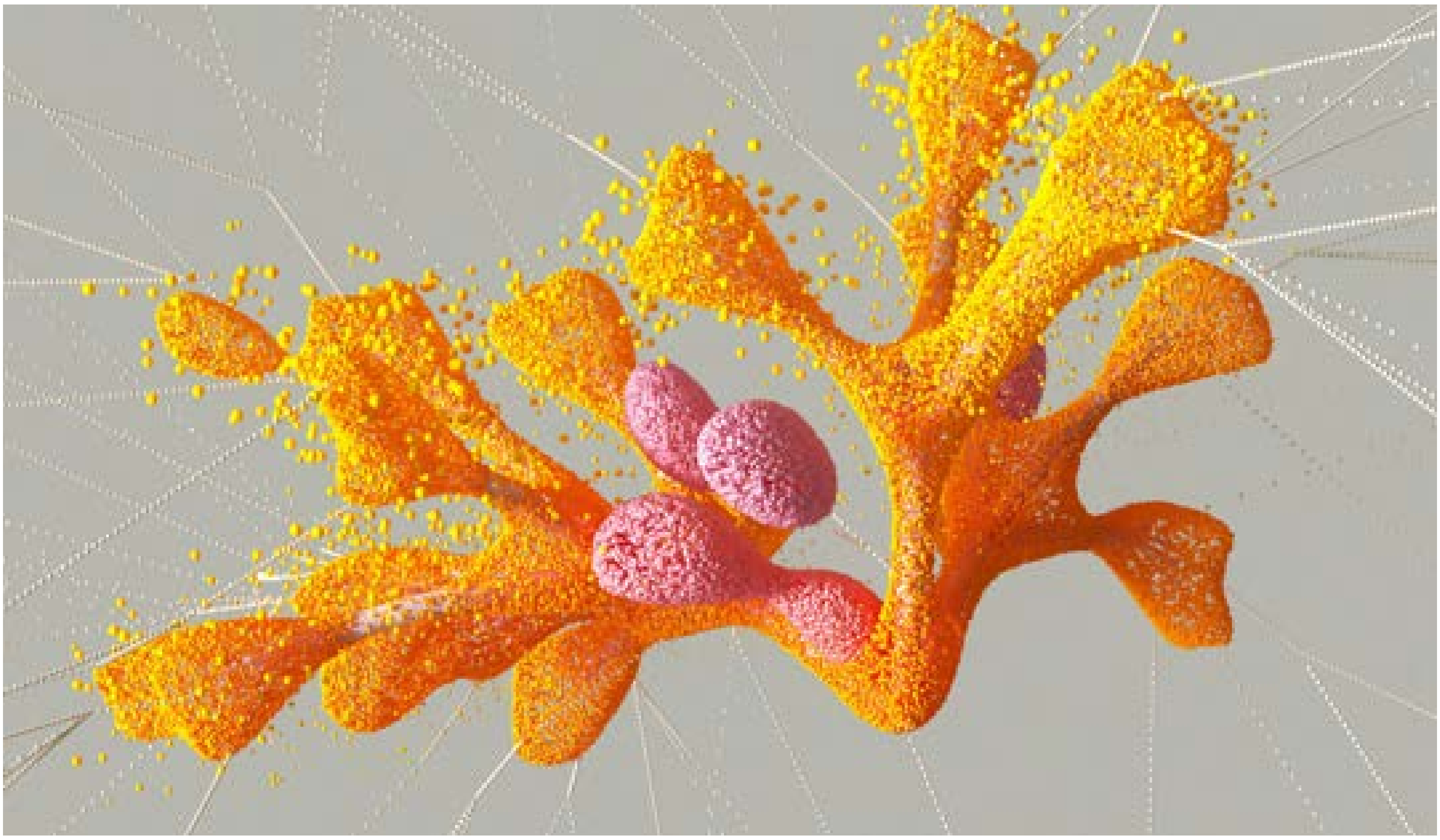


A STRATEGIC FRAMEWORK FOR IMPLEMENTING GENERATIVE AI

The successful adoption of generative AI within an organisation requires a well-structured strategic framework that includes training and upskilling, cultural empowerment, and the role of experimentation. Here we expand on these critical components to provide a comprehensive approach to AI adoption.

❶ BE CLEAR ABOUT WHY THE ORGANISATION IS INTRODUCING AI

Helping employees to trust the reasons for change and addressing concerns about job security (provided they are genuine) is vital to encourage genuine adoption. According to a CNBC SurveyMonkey Workforce survey, 60% of employees who use AI regularly reported they worry about its impact on their jobs. Yet Seventy-two percent of respondents who use the technology recognise that automation significantly increases productivity. As such, people will need assurance that this will bring benefits to how they work, such as freeing up time to focus on more interesting, strategic, and productive tasks.



❷ TRAINING AND UPSKILLING

Whilst employees do not need to understand how the AI actually works in order to use it, training is essential for three reasons.

GARBAGE IN, GARBAGE OUT

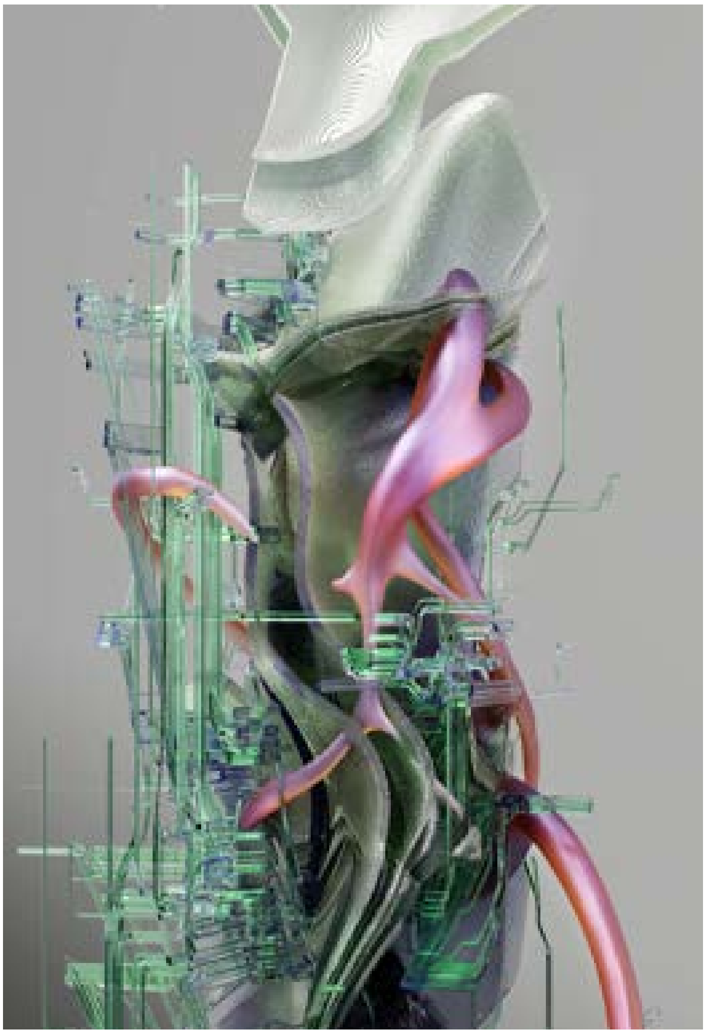
The principle of "Garbage In, Garbage Out" emphasises the importance of high-quality input for effective AI output. The quality of the prompt is fundamental in influencing the quality of the AI's response. In short, if the prompt going in is garbage, the output will be garbage. The danger here, particularly in the early stages of adoption, when users are exploring AI perhaps for the first time, is that they will unwittingly put in a poor prompt and in turn receive a poor response – this in turn will taint their view as to the usefulness of the AI, creating an otherwise avoidable barrier to its subsequent use and adoption.

UPSKILLING FOR FUTURE ROLES

AI's transformative potential necessitates that employees are equipped with new skills. Upskilling programmes should focus on enhancing digital literacy, understanding AI tools, and developing critical thinking skills to evaluate AI outputs. This not only mitigates the fear of job displacement but also empowers employees to use AI creatively and effectively in their roles.

UNDERSTANDING AI LIMITATIONS

Training is also vital to educate employees on the limitations of AI, such as the phenomenon of hallucinations where AI generates incorrect or nonsensical outputs. Awareness of these limitations helps in setting realistic expectations and leveraging AI effectively. Ethan Mollick's concept of cyborgs (humans augmented by AI) and centaurs (collaborative human-AI teams) can be particularly useful. Training can guide employees on when to use AI independently (cyborg approach) and when to integrate it into collaborative processes (centaur approach), optimising the use of AI based on task requirements.



❸ INTERNAL COMMS

Great internal communications are fundamental to the successful adoption and innovation of AI within any organisation. Clear, consistent, and engaging communication ensures that all employees understand the vision, benefits, and practical applications of AI, fostering a culture of acceptance and enthusiasm rather than fear and resistance. Effective internal communication can bridge the gap between leadership ambitions and employee execution, ensuring that AI initiatives are aligned with the organisation's goals and values.

Here is an evidence-based comprehensive approach to internal communications for AI innovation, rooted in three key pillars: Insight and Analysis, Strategy and Implementation, and Measurement and Impact.

INSIGHT AND ANALYSIS

The first step is to gain a deep understanding of the organisation's current proficiency levels with AI and the comfort of its employees in adopting new technologies. This involves conducting thorough assessments to gauge existing knowledge, skills, and attitudes towards AI.

Steps to Increase Proficiency Levels:

- Conducting surveys and interviews to assess current AI literacy and comfort levels among employees.
- Developing customised training programmes to address specific needs and knowledge gaps
- Start with small-scale AI projects to demonstrate potential benefits and build confidence among employees
- Identify and train enthusiastic employees to become AI advocates who can support and inspire their peers.

Be open about the unknowns: you should acknowledge the potential unintended consequences of AI adoption, such as job displacement fears and ethical considerations. By addressing these openly and providing strategies to mitigate them, such as retraining programmes and ethical guidelines, leaders will build trust.

CREATING A STRATEGY THAT IS ROOTED IN THE COMPANY'S VALUES AND GOALS

The second pillar involves developing a strategic communication plan that aligns with the organisation's core values and long-term objectives. The organisations that will see the most success are those who's values and culture are deeply rooted in championing curiosity, which is essential for fostering a culture of innovation. By embedding these values into our AI strategy, we ensure that employees are motivated and engaged in the adoption process.

KEY INGREDIENTS FOR AN EFFECTIVE GENERATIVE AI STRATEGY:

- ENCOURAGE KNOWLEDGE SHARING – Curiosity is contagious. Encouraging the teams to share what they find creates an environment of open discovery and shared learning. This should be encouraged through continued communications such as dedicated internal Teams channels, regular knowledge-sharing sessions, and collaborative platforms where employees can post their findings, discuss AI developments, and share practical applications. Such initiatives not only spread knowledge but also inspire others to explore AI.

- CHAMPION AND REWARD – Celebrating acts of curiosity and innovation is crucial to fostering a positive and motivating environment. It is crucial to recognise and reward employees who take initiative in exploring AI and sharing their insights. This includes both formal recognition programmes and informal acknowledgments in team meetings or company-wide communications. By highlighting and rewarding these behaviours, we reinforce the importance of curiosity and continuous learning, motivating others to engage actively in AI adoption.

- EMPOWERMENT: Senior management must foster an environment where employees feel trusted and supported to explore AI. This involves providing autonomy and encouraging experimentation without the fear of failure. Empowerment leads to a more engaged and proactive workforce willing to innovate with AI

- EXPLORATION: Organisations should ensure that employees have access to AI tools and the necessary time to experiment. This requires a balanced approach where sufficient parameters and support structures are in place to guide exploration while allowing creative freedom. Structured time for exploration can lead to discovering novel applications of AI that drive business innovation.

By creating a strategy that resonates with the company's mission and values, we can drive a more cohesive and enthusiastic adoption of AI.

MEASUREMENT AND IMPACT

The final pillar is establishing a robust measurement framework to track progress, assess performance, and demonstrate the impact of AI initiatives. This involves setting clear objectives, using mixed methods of data collection, and regularly monitoring and reporting on AI progress. Our approach ensures that employee feedback and insights are integral to the evaluation process, helping to refine and improve AI strategies continuously.

KEY COMPONENTS

- SETTING CLEAR OBJECTIVES:
  Defining measurable goals for AI initiatives that align with organisational objectives.
- USING MIXED METHODS:
  Combining quantitative data (e.g., surveys, usage analytics) with qualitative data (e.g., focus groups, interviews) to gain a comprehensive view of AI impact.
- REGULAR MONITORING:
  Establishing a regular cadence for monitoring and reporting on AI progress, ensuring transparency and continuous improvement.
- STAKEHOLDER ENGAGEMENT:
  Keeping stakeholders informed and engaged with regular updates on AI performance, including successes, challenges, and areas for improvement

❹ ROLE OF EXPERIMENTATION

Acting as a further catalyst to innovation is the role of experimentation, where that experimentation is not only encouraged through culture but actively sponsored by the organisation.

CULTIVATE EXPERIMENTATION CULTURE

Organisations should foster a culture of continuous learning and adaptation. This involves not just structured experiments but also informal, everyday innovations driven by employees at all levels. Encouraging a mindset where employees feel empowered to 'plant, prune, and weed' their ideas can lead to more organic and sustainable innovation. On a more fundamental point: we must experiment, in order to learn. It's only when we try out new ways of working that we will learn how to best work with Generative AI. Even as many of those initial tries won't result in new innovations, the act of experimenting results in generative AI skillsets across the organisation.

INNOVATION THROUGH EXPERIMENTS

Encouraging structured experimentation can significantly drive AI innovation. Organisations should implement programmes where employees conduct controlled experiments to explore new AI applications. This iterative process helps in refining AI usage and discovering practical solutions that add value.

CROSS-FUNCTIONAL COLLABORATION

Effective experimentation involves teams that combine domain expertise with technical AI knowledge. This collaboration ensures that experiments are grounded in practical use cases and technical feasibility. Organisations may also benefit from involving external consultants who bring specialised knowledge and an outside perspective to the experimentation process.

ITERATIVE FEEDBACK LOOPS

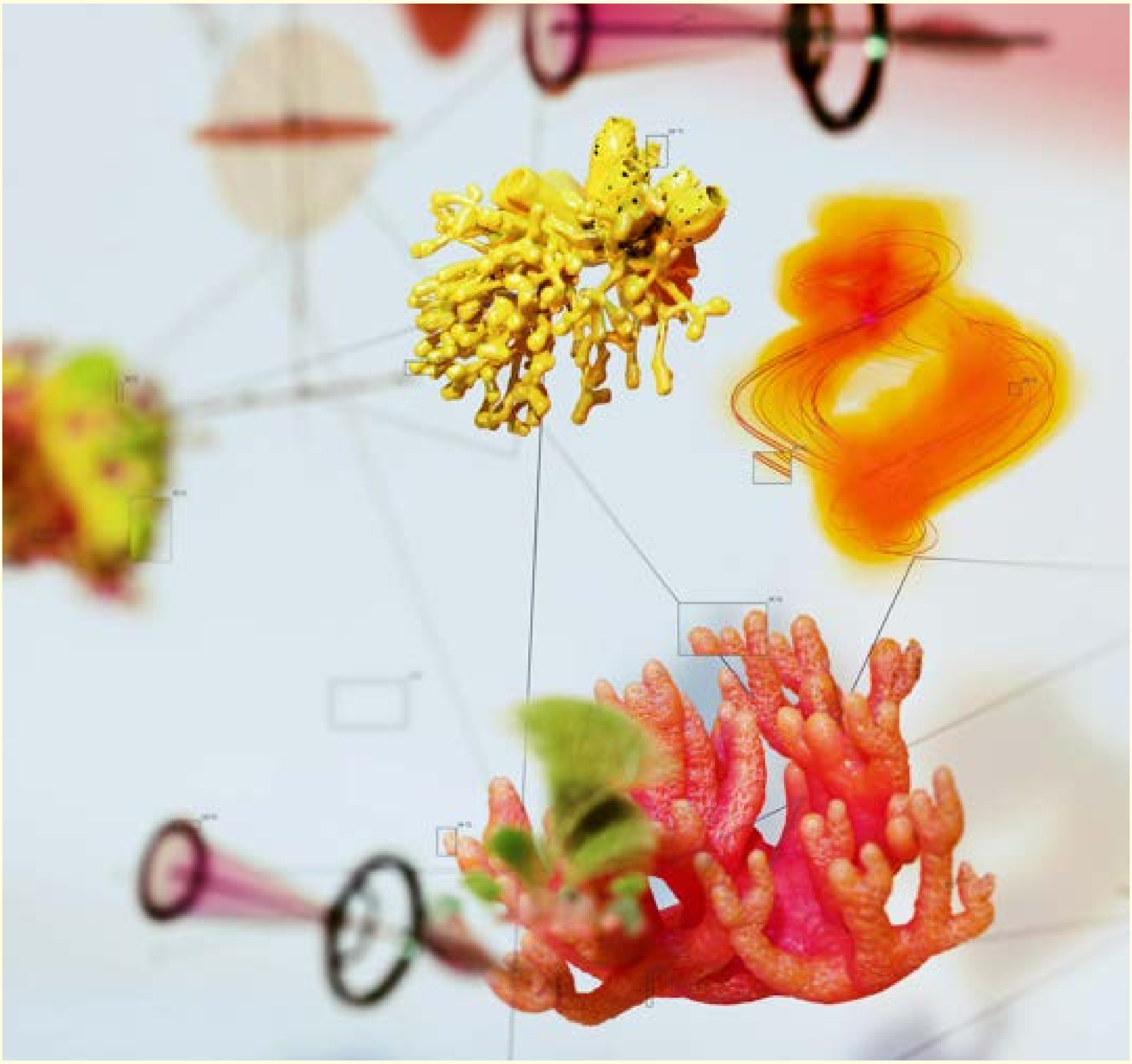
Establish iterative feedback loops where outcomes of experiments are regularly reviewed, and learnings are shared across the organisation.

MONITORING AND SCALING

It's crucial to monitor the outcomes of these experiments to identify successful applications that can be scaled across the organisation. Establishing metrics for success and documenting learnings helps in refining the AI adoption strategy and replicating successful initiatives.

By focusing on these three pillars—training and upskilling, cultural empowerment, and structured experimentation—organisations can create a robust framework for implementing Generative AI.

This approach not only facilitates the smooth adoption of AI but also drives continuous innovation, ensuring that AI's potential is fully realised within the business context.



CONCLUSION

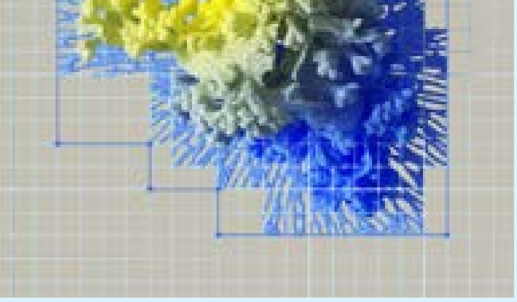
The transformative potential of Generative AI is undeniable. From enhancing productivity and creativity to driving significant cost efficiencies, AI stands to revolutionise how organisations operate, compete, and deliver value. However, realising this potential requires a thoughtful, strategic approach that balances top-down leadership with bottom-up innovation.

Leadership must set clear ambitions, legitimise AI use across the organisation, and establish ethical and practical parameters for AI application. This strategic direction is crucial in fostering a supportive environment where AI can thrive. Concurrently, empowering employees to explore, experiment, and integrate AI into their daily tasks ensures widespread and meaningful adoption. This dual approach leverages the unique strengths of both leadership and employees, fostering a culture of innovation and collaboration.

Great internal communications play a fundamental role in this process. Clear, consistent, and engaging communication ensures that all employees understand the vision, benefits, and practical applications of AI, fostering a culture of acceptance and enthusiasm. A truly comprehensive approach to internal communications is rooted in insight and analysis, strategy and implementation, and measurement and impact, ensuring that AI initiatives are aligned with organisational goals and values.

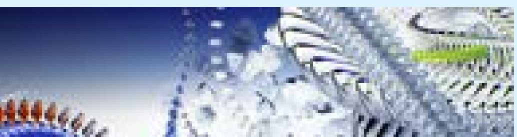
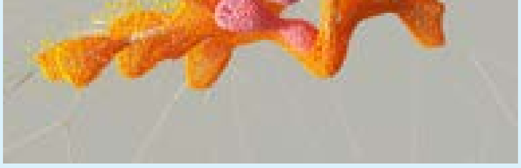
Training and upskilling employees are essential to address the nuances of AI, from understanding its limitations to leveraging its full potential. A structured framework for experimentation encourages innovation, while continuous measurement and adaptation ensure that AI initiatives remain aligned with business objectives and yield tangible benefits.

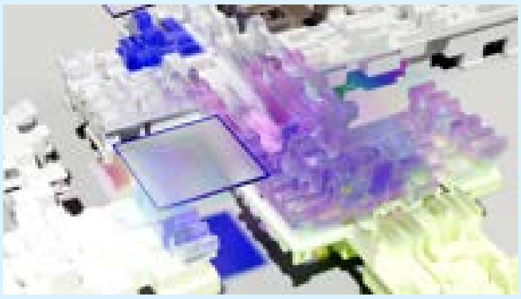
In conclusion, the successful adoption of Generative AI within organisations requires a balanced and integrated approach. By combining top-down strategic leadership with bottom-up innovation and engagement, organisations can unlock the full potential of AI, driving significant value and transformative change. Embracing this dual approach will not only enhance productivity and efficiency but also foster a dynamic and forward-thinking organisational culture ready to thrive in the AI-driven future.

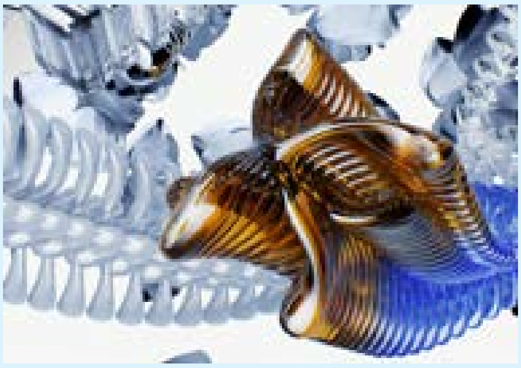


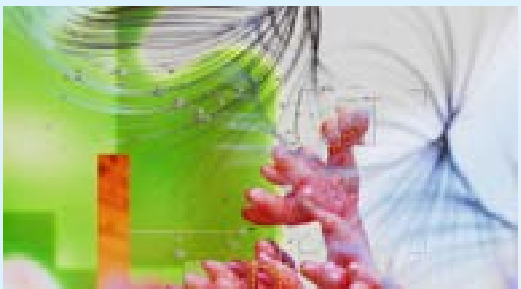
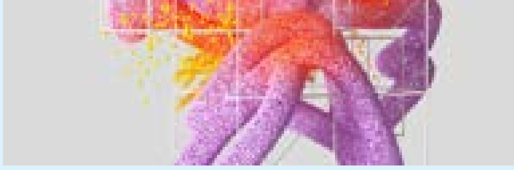


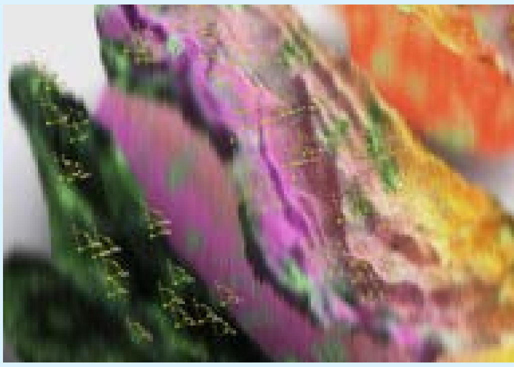


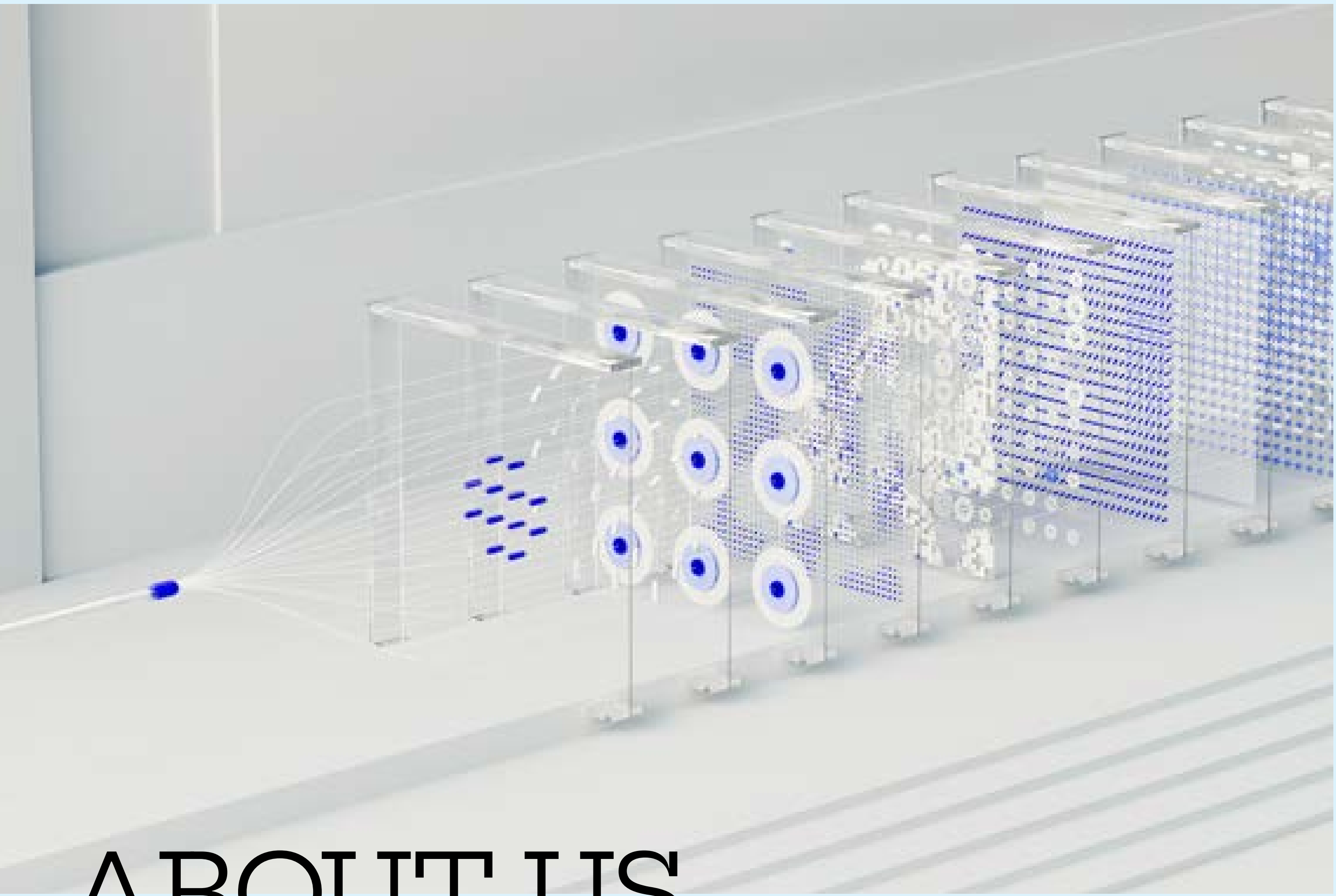







ABOUT US

GRAYLING CONNECT

Grayling Connect is Grayling UK's new employee engagement and change management service, creating and delivering data and insight-driven strategies for organisations to drive engagement and growth. Grayling Connect enables organisations to go beyond conventional approaches to empower them to foster their talent and deliver engaging, and impactful internal engagement strategies.

The service is supported by Grayling's expertise in strategy, digital insights, creative capabilities and our understanding of data-led behavioural science to help clients navigate internal challenges and opportunities, and truly transform. Seamless integration across all internal communications disciplines and broader communications mix means Grayling Connect offers 360º vision, linking reputation with employee experience.

AINIGMA

Ainigma is a boutique technology consultancy specialising in driving people-first implementation of Generative AI. From our offices in London and Amsterdam, we help leaders develop their AI Strategy, host AI-Powered Innovation Sprints and run change programmes that upskill and engage all employees.

Rooted in change management and creative culture, our programmes empower your employees for success.

Together we guide and shape your generative AI journey and drive value for your business, your people and your product.

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Artificial Brain BosonQ Psi Quantum Inspire

Sustainable Oceans through Quantum Tech:

Shaping the Future of Marine Conservation and Maritime Operations

WHITE PAPER

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Overview

Marine ecosystems play a pivotal role in sustaining life on Earth yet face mounting threats from various sources such as harmful algal blooms, pollution, and inefficient maritime operations. The intricate balance of these ecosystems is imperiled, necessitating sophisticated solutions to ensure their preservation and the sustainable management of marine resources. Within the vast expanses of oceans, lakes, and rivers, both beneficial and harmful algae coexist. Beneficial algae contribute to the ecosystem by absorbing carbon dioxide and releasing oxygen, enhancing the vital dissolved oxygen levels for marine organisms.

However, the proliferation of harmful algae due to industrial and agricultural runoff introduces excess nutrients into water bodies, a phenomenon known as eutrophication. This excess nutrient influx fosters the growth of Harmful Algal Blooms (HABs), which discharge toxins into the water, posing grave threats to marine life and depleting dissolved oxygen levels. Traditional land-based methods of analysis fall short in effectively monitoring and mitigating these phenomena.

In addition to the challenges posed by harmful algal blooms, inefficient maritime operations exacerbate the threats to marine ecosystems. Activities such as pollution from air and waterborne contaminants, noise pollution, and habitat disruption from maritime operations endanger marine life and increase the risk of catastrophic oil spills. The cumulative impact of these factors underscores the urgent need for innovative approaches to marine conservation and management.

Conventional computational methods have limitations in accurately identifying and addressing these threats, highlighting the necessity for a paradigm shift in marine conservation strategies. Quantum technology emerges as a promising avenue for addressing the multifaceted challenges faced by marine ecosystems. Through its unparalleled computational power and capability to process vast amounts of data simultaneously, quantum technology offers new possibilities for environmental monitoring, species classification, and optimization of maritime logistics.

By harnessing the potential of quantum technology, it becomes feasible to develop advanced models and algorithms that enhance our understanding of marine ecosystems and facilitate informed decision-making for their preservation and sustainability.

In this white paper, we explore the transformative potential of quantum technology in tackling the complexities of marine conservation.

From real-time environmental monitoring to the optimization of maritime operations, quantum technology presents innovative solutions that can revolutionize the way we approach marine life preservation and ecosystem sustainability. By leveraging the unique capabilities of quantum computing, we can pave the way towards a more resilient and thriving marine ecosystem, ensuring the continued well-being of both marine life and human society.

Introduction – Quantum Technology

Quantum technology refers to a broad field of science and engineering that explores and exploits the principles of quantum mechanics to develop new technologies with capabilities far beyond those of classical technologies. At its core, quantum technology harnesses phenomena such as superposition and entanglement, which are inherent to quantum mechanics, to manipulate and process information in fundamentally different ways from classical systems. Examples of quantum technology include quantum computing, quantum cryptography, quantum sensing, and quantum communication.

These emerging technologies have the potential to revolutionize various fields, from computational science and cybersecurity to healthcare and materials science, by offering unprecedented levels of speed, security, and computational power. Quantum technology represents a revolutionary approach to computing and information processing. At its core, quantum computing harnesses the power of quantum bits, or qubits, which can exist in multiple states simultaneously. This inherent parallelism enables quantum computers to tackle complex problems exponentially faster than classical computers.

Quantum Optimization

Quantum optimization algorithms provide powerful tools for solving combinatorial optimization problems with unprecedented efficiency, offering potential applications in areas such as logistics, finance, and drug discovery. As quantum technology continues to advance, its transformative potential across various domains, including quantum machine learning and optimization, holds immense promise for addressing complex real-world challenges. Overall, the integration of quantum technology into marine conservation strategies promises to enhance our understanding of marine ecosystems and empower us to make informed decisions for their preservation and sustainable management.

Quantum Machine Learning (QML)

One of the key areas of innovation in quantum technology is Quantum Machine Learning (QML), which explores how quantum computing can enhance machine learning algorithms and data analysis techniques.

By leveraging the unique properties of quantum systems, such as superposition and entanglement, QML promises to revolutionize fields such as pattern recognition, optimization, and data classification.

Quantum Simulation (QS)

Another exciting frontier in quantum technology is Quantum Simulation (QS), with profound implications for Computational Fluid Dynamics (CFD) and engineering applications. Unlike traditional computers that struggle with complex simulations of many-body systems, quantum computers exploit the principles of quantum mechanics to directly model these systems. This allows for unparalleled accuracy and efficiency in simulating fluid flow, material behavior, and other intricate phenomena crucial to engineering design and optimization.

QS promises to revolutionize many fields by enabling the simulation of previously intractable problems, leading to breakthroughs in design, performance, and efficiency.

Quantum Optimization Use Cases

Maritime Route Selection Optimization

Optimizing sea routes for ships, as well as other maritime operations, faces the challenge of handling numerous variables to achieve the best outcomes. From wind patterns to marine life presence, these factors significantly impact navigation efficiency and operational effectiveness.

Maritime route selection optimization using quantum optimization represents a cutting-edge approach to enhancing efficiency and sustainability in marine transportation. Traditional route optimization methods often struggle to account for the dynamic and complex nature of marine environments, leading to suboptimal routes, increased fuel consumption, and higher emissions. Quantum optimization algorithms, however, leverage quantum computing principles to quickly analyze vast amounts of data and identify optimal routes based on multiple variables, such as weather patterns, sea currents, traffic density, and fuel consumption rates, all while considering real-time changes. This ability to rapidly process complex data sets and find optimal solutions makes quantum optimization superior to classical methods, leading to significant reductions in fuel usage, greenhouse gas emissions, and overall transportation costs for maritime industries.

Moreover, the application of quantum optimization in maritime route selection has profound implications for marine conservation and life. By minimizing fuel consumption and emissions through optimized route planning, quantum-based approaches contribute directly to reducing the ecological footprint of maritime transportation activities. This reduction in environmental impact helps mitigate the negative effects of shipping on marine ecosystems, including noise pollution, habitat disruption, and the risk of marine accidents such as oil spills. Moreover, by optimizing routes to avoid sensitive marine habitats and biodiversity hotspots, quantum optimization supports marine conservation efforts by reducing the likelihood of ship strikes on marine mammals, protecting critical spawning grounds for fish populations, and minimizing the overall ecological disturbance caused by maritime traffic. In essence, quantum optimization not only enhances the efficiency and cost-effectiveness of maritime transportation but also promotes sustainable practices that safeguard marine ecosystems and biodiversity for future generations.

Marine Hybrid Propulsion: Transient Control Optimization

The increasing demands for energy conservation and environmental protection have led to stricter regulations on ship energy efficiency. To meet these requirements, the shipping industry has accelerated the development of marine hybrid propulsion systems (MHPS). However, optimizing power distribution through intelligent algorithms can result in ship oscillations and speed fluctuations, negatively impacting the overall system's economy.

Optimizing marine hybrid propulsion systems (MHPS) is crucial for meeting the increasingly strict regulations on ship energy efficiency and reducing environmental impact. These systems offer energy-saving and environmentally friendly solutions, but the optimization of power distribution through traditional algorithms can result in oscillations and speed fluctuations in ships that negatively impact the system's economy.

To address these challenges and improve energy control, there is a need for new power systems and advanced optimization technologies. This has led to the development of quantum computing-based approaches for MHPS optimization. Quantum optimization algorithms offer a promising solution to the computational challenges faced by classical algorithms and computers in optimizing MHPS. One approach, Quantum Inspired Evolutionary Optimization (QIEO), is a heuristic method that can systematically find better solutions for multi-time interval discrete optimization problems. QIEO considers multiple objectives, constraints, and input parameters to optimize power delivery in MHPS. By minimizing energy consumption, reducing greenhouse gas emissions, and meeting regulatory requirements, QIEO can enhance the performance of MHPS and power delivery efficiency.

In addition, quantum computing techniques, such as Quantum Annealing and Quantum Gate-based computing, are particularly relevant for quadratic unconstrained binary optimization (QUBO) problems, which are common in combinatorial optimization.

These techniques leverage the adiabatic evolution under changing external conditions to find low-energy states that represent optimal solutions for optimization problems. This enables faster and more accurate simulation-based optimization, leading to improved energy efficiency and reduced environmental impact of MHPS.

Simulation-based optimization covers a range of approaches where an optimal (or close to optimal) solution is found by simulating a system for many potential decision-variable configurations. These include methods with theoretical guarantees, such as dynamic programming, as well as metaheuristic approaches, such as evolutionary algorithms and particle swarm optimization. The simulation of MHPS using Quantum algorithms can optimize performance while reducing greenhouse emissions, reducing impacts on marine ecosystems.

Quantum simulation-based optimization strategies offer a new horizon for the shipping industry, addressing the complexities of MHPS and providing more effective power distribution solutions. By leveraging quantum computing, we can overcome the limitations of classical algorithms and computers, achieving higher accuracy, real-time analysis, and improved performance in MHPS. This will contribute to the goal of energy conservation, environmental protection, and sustainable shipping practices.

QIEO Algorithm for Tackling Computational Hurdles:

Linear and non-linear characteristics, and multiple criteria and objectives, are making these optimization problems. It is challenging for classical algorithms and classical computers. Firstly, it is hard to model these problems and get higher accuracy results as well. Secondly, real-time analysis of these hybrid prolusion systems becomes more difficult for conventional computers.

For example, Quantum Annealing and Quantum Gate-based computing provide a more limited form of quantum computing based on adiabatic evolution under gradually changing external conditions. Quantum Annealing is specifically relevant for quadratic unconstrained binary optimization (QUBO) problems, which are a problem class within combinatorial optimization. A coupled lattice of qubits is first initialized into an easy-to-prepare low-energy ground state, and then the qubit lattice is slowly controlled so that it remains in a low-energy state, which eventually represents the solution of an optimization problem.

These optimization strategies focus on finding approximate solutions for nonlinear problems that are not amenable to exact methods and can efficiently reduce emissions by optimizing MHPS, hence, improving marine life.

BQP's latest case study on Hybrid Quantum-Classical Finite Method (HQCFM) significantly improves in an existing Quantum Linear Solver Algorithm (QLSA). The focus of the HQCFM was to solve the Ax = b linear system, that solves 2D, transient, incompressible, viscous, non-linear, and coupled the Burger's equation. Such a demonstration of using a quantum linear equation solver coupled with a transient problem is unprecedented.

Therefore, advanced simulations using quantum-based algorithms, and frameworks breakthrough innovation for important performance of marine propulsion systems for large cargo ships while reducing greenhouse emissions.

Sustainable Maritime Route Optimization

In the vast expanse of our oceans, where maritime trade routes intersect with delicate marine ecosystems, efficient ship navigation is crucial. Addressing the complexities of modern navigation while preserving marine environments requires innovative solutions. Quantum-inspired algorithms are emerging as a promising solution to address the complexities of ship navigation and enable the conservation of marine ecosystems. Maritime route planning and ship navigation have traditionally been governed by standards and norms set forth by the International Maritime Organization (IMO). These regulations aim to reduce the risk of shipwrecks and enhance economic benefits for maritime navigation. Increasing complexity of navigation tasks, coupled with the challenges posed by factors such as wind, waves, weather and high-resolution data requirements. Factoring in routes with fragile ecosystems adds another level of complexity, creating a pressing need for more sophisticated path-planning algorithm

Navigational Challenges and the Need for Innovation

Existing maritime path planning algorithms often struggle with low accuracy and operational efficiency, particularly when faced with multiple constraints and long-distance navigation tasks. Traditional approaches have found it difficult to adapt to the intricacies of multi-constraint conditions and high-resolution data demands. However, the emergence of quantum-inspired algorithms offers a promising avenue for overcoming these challenges.

Benefits of Quantum-Inspired Route Optimization

The key advantage of quantum-inspired algorithms like SPA* lies in their ability to handle the immense computational complexity inherent in maritime route optimization. By harnessing the power of quantum computing, these algorithms can explore vast search spaces more efficiently, leading to faster and more accurate solutions. This is particularly beneficial for long-distance planning tasks, where traditional algorithms often struggle to find optimal routes within reasonable timeframes.

Moreover, quantum-inspired algorithms have the potential to revolutionize maritime route optimization by enabling real-time decision-making and adaptability to dynamic environmental conditions. By continuously analyzing sensor data and adjusting navigation plans accordingly, ships can navigate more safely and efficiently while minimizing their ecological footprint.

This not only benefits the marine ecosystem but also enhances the economic viability of maritime trade and transportation.

Application of quantum-inspired algorithms in maritime route optimization aligns with broader efforts to promote sustainable development and environmental conservation. By optimizing shipping routes to minimize fuel consumption and emissions, these algorithms contribute to reducing the carbon footprint of maritime transportation, thus mitigating climate change impacts on marine ecosystems.

As technology continues to advance, quantum-inspired algorithms will play an increasingly vital role in shaping the future of maritime navigation and environmental stewardship.

Maritime Canals Scheduling Optimization

Quantum optimization has the potential to revolutionize the planning and management of maritime canals, offering unprecedented efficiency and sustainability benefits across various areas of application. Quantum optimization algorithms can rapidly analyze complex data sets and identify optimal configurations for maritime canal networks. This capability is particularly valuable for improving navigation efficiency, reducing congestion, and minimizing transit times within canal systems, leading to significant cost savings and operational enhancements for maritime industries.

The application of quantum optimization in the planning and management of maritime canals holds substantial promise for marine life conservation.

By optimizing canal routes to minimize environmental impacts, such as habitat fragmentation and water pollution, quantum-based approaches can help mitigate the negative effects of canal construction and operation on marine ecosystems. Additionally, quantum optimization can facilitate the design of eco-friendly canal features, such as fish passages and shoreline buffers, to enhance habitat connectivity and promote the natural movement of aquatic species through canal networks.

Overall, by promoting sustainable canal management practices and minimizing ecological disturbance, quantum optimization contributes to the preservation of marine biodiversity and the long-term health of coastal ecosystems.

Maritime Cargo Ship Scheduling Optimization

In maritime industries, quantum optimization presents a transformative opportunity to enhance efficiency and sustainability in shipping operations, port management, and offshore activities. By leveraging quantum computing principles, maritime stakeholders can optimize cargo ship scheduling, port logistics, and offshore supply chain management, leading to significant improvements in operational efficiency, cost savings, and environmental sustainability. Quantum optimization enables the rapid analysis of complex data sets and the identification of optimal routes, schedules, and resource allocations, thereby streamlining maritime operations, reducing fuel consumption, and minimizing ecological impact.

By optimizing shipping routes, port operations, and offshore activities, quantum-based approaches can minimize the ecological footprint of maritime operations, reduce the risk of environmental accidents, and mitigate the negative effects of human activities on marine ecosystems.

By promoting sustainable practices and minimizing environmental impact, quantum optimization contributes to the preservation of marine biodiversity, the protection of sensitive habitats, and the long-term health of coastal and marine environments, ensuring a more sustainable future for our oceans and the life they support.

In conclusion, the integration of these techniques into various maritime operations presents significant opportunities for enhancing efficiency, reducing costs, and minimizing environmental impact.

By harnessing the power of quantum computing to handle large numbers of variables and reach global optima, maritime operators can navigate the complexities of the marine environment with precision and resilience.

Quantum Machine Learning (QML) Use Cases

The proliferation of harmful algal blooms (HABs) poses a significant threat to marine ecosystems and water bodies worldwide, fueled by excessive industrial and agricultural runoff containing nutrients and chemicals. While certain types of algae play a vital role in oxygen production and ecosystem health, the overabundance of harmful species can have devastating effects on marine life and water quality.

Detection, classification, and removal of these harmful blooms are critical for mitigating their impact and preserving aquatic ecosystems.

Satellite data coupled with machine learning algorithms offer a powerful tool for detecting and classifying algae blooms on a large scale. By analyzing spectral signatures and spatial patterns captured by satellites, machine learning models can accurately identify and classify different types of algae present in water bodies.

However, while classical machine learning techniques have shown promise in this domain, quantum machine learning (QML) holds even greater potential for enhancing algae bloom classification accuracy and efficiency.

Quantum machine learning harnesses the computational power of quantum computing to tackle complex classification tasks more effectively than classical machine learning methods. By leveraging quantum algorithms and quantum data processing techniques, QML models can handle high-dimensional data more efficiently, capture subtle features in spectral signatures, and improve classification accuracy, particularly in scenarios with noisy or sparse data. As a result, quantum machine learning offers a promising approach to enhance the detection and classification of harmful algal blooms, enabling more proactive and effective management strategies to safeguard marine life and water quality.

QML for Hyperspectral Data Classification

On a local scale, traditional methods of sampling water for algae identification provide valuable insights into the types present, yet they offer only a partial understanding of the overall algae composition. Given the vast diversity of algae species and their abundance in water bodies, achieving a comprehensive understanding demands a broader perspective. This necessitates transitioning to an Earth observation satellite viewpoint, offering a panoramic view of aquatic environments. Hyperspectral Earth observation satellites, with their ability to capture detailed spectral information across a wide range of wavelengths, emerge as a potent tool for this task. Each algae species exhibits a unique spectral signature, enabling precise classification and quantification from satellite imagery.

In comparison to classical machine learning approaches, quantum machine learning (QML) holds distinct advantages in performance and classification accuracy, especially when dealing with large datasets such as hyperspectral imagery. Research indicates that QML can outperform classical methods in various classification tasks, showcasing its potential to revolutionize algae bloom detection and characterization.

The complexity of hyperspectral data, coupled with the potential overlap in spectral signatures between water and different algae species, poses challenges for classical machine learning models. However, QML excels in disentangling intricate spectral patterns and discerning subtle differences, making it particularly adept at classifying overlapping spectral signatures.

Moreover, in scenarios where spectral signatures of different algae species exhibit minimal distinctions or overlap, QML demonstrates its superiority in classification. Its inherent ability to leverage quantum computing principles, such as superposition and entanglement, allows QML models to explore a vast solution space efficiently and uncover nuanced relationships within data.

By harnessing the computational power of quantum algorithms, QML transcends the limitations of classical machine learning, offering unparalleled accuracy and efficiency in algae classification from hyperspectral satellite imagery. As advancements in quantum computing continue to accelerate, the integration of QML into Earth observation systems promises to revolutionize our understanding of aquatic ecosystems and facilitate proactive management strategies for preserving water quality and marine biodiversity.

Once harmful algal blooms (HABs) are accurately detected and classified using advanced technologies like hyperspectral Earth observation satellites and quantum machine learning, targeted measures can be implemented to mitigate their impact and restore water quality. Strategies for clearing out HABs vary depending on factors such as the type of algae present, the severity of the bloom, and the specific characteristics of the water body. Mechanical methods such as skimming, filtering, and aeration can be employed to physically remove algae from the water surface and improve oxygen levels.

Additionally, biological approaches such as the introduction of algicidal compounds or the deployment of algae-consuming organisms like zooplankton can help control algae populations and prevent bloom recurrence. Chemical treatments may also be utilized to disrupt algal growth or neutralize toxins produced by certain species.

By leveraging the information gleaned from algae detection and classification efforts, targeted interventions can be tailored to address specific HABs and restore affected water bodies to a healthier state, benefiting both aquatic ecosystems and the communities that rely on them.

Quantum CNNs for Real-Time Underwater Species Identification:

Marine life conservation is crucial for maintaining a healthy ecosystem, and rapid detection and identification of underwater species is vital to achieving this objective. However, traditional imaging methods utilized in underwater species identification often face challenges such as low light, murky waters, and image blur, rendering the process time-consuming, costly, and sometimes inaccurate. Leveraging machine learning methods such as quantum convolutional neural networks (CNNs), however, offer significant possibilities. These quantum-enhanced real-time computer vision technologies can improve accuracy while decreasing computational time and required dataset sizes.

By using quantum CNNs, it can advance the image processing and identification of underwater species for improving marine life detection. It will enable underwater identification and tracking of species, including those that are rare or endangered within their habitats, providing crucial data for conservation efforts. Furthermore, with the help of quantum image processing, scientists can quickly detect and locate harmful marine waste, such as plastic waste and oil spills.

Machine learning methods are increasingly used for object recognition under such adverse conditions.

These enhanced object recognition methods of images taken from AUV's have potential applications in underwater pipeline and optical fiber surveillance, ocean bed resource extraction, ocean floor mapping, underwater species exploration, etc.

While the classical machine learning methods are very efficient in terms of accuracy, they require large datasets and high computational time for image classification. Therefore, efficient algorithms are needed for better speed of computation with fewer computing resources.

Previous research has showcased hybrid quantum machine learning methods that show an efficiency greater than 65% and reduction in run-time by one-third and require 50% smaller dataset sizes for training the models compared to classical machine learning methods.

This innovative use of technology can be a game-changer in marine conservation, as it can help scientists identify key areas where conservation efforts can be focused, protecting indigenous marine life and ecosystems. It can play a vital role in surveillance and monitoring, identifying species at risk, and informing scientific research of these habitats.

As a result, it will also help policymakers prioritize conservation measures and enhance our understanding of marine life.

By leveraging quantum CNNs and advanced imaging technologies, this could have a significantly positive impact on identifying and protecting marine species. These techniques provide a valuable tool for improving our understanding of the underwater world, enabling effective conservation efforts, and helping to save precious marine lives.

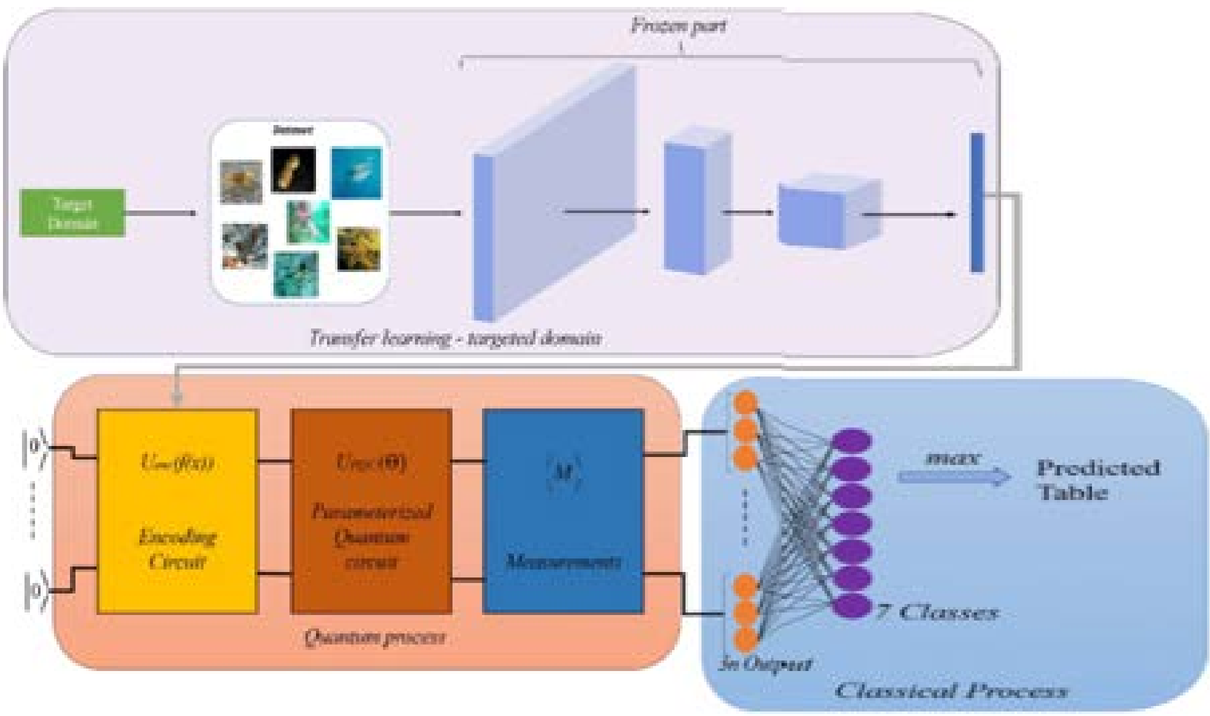


Figure: Hybrid Quantum Classical Convolutional Neural Network

The figure showcases the initial stage involves a classical Convolutional Neural Network (CNN) for feature extraction. Subsequently, the second phase employs a Quantum circuit for classification purposes.

Quantum Based Climate Modeling and Prediction

Quantum for Climate Change Detection:

In the space and aerospace industry, various challenges arise in resource allocation, planning, object scheduling, and AI model training. These tasks often demand significant time, memory space, and electrical consumption.

One innovative approach to address these challenges is the use of quantum approaches. Quantum techniques have been employed to tackle real-world intractable computational problems in industries like aerospace, including flight-gate assignment and satellite mission planning for Earth observation. They have also shown potential in numerical weather modeling, climate simulation, energy optimization, renewable energy, and quantum AI for climate change detection.

However, demonstrating a clear advantage of quantum techniques over conventional classical approaches is still a work in progress. Quantum machines are still in the improvement stages, and it is crucial to determine which practical problems will truly benefit from quantum machines and algorithms.

There is currently an ongoing effort to identify complex computational problems in the space and aerospace industry that can be handled more efficiently using quantum machines compared to supercomputers. Additionally, researchers are exploring how to leverage both quantum machines and supercomputers to maximize their potential and achieve superior results.

There are two possible quantum approaches to tackle this problem:

1. Variational Quantum Algorithms (VQAs):

VQAs are a class of Quantum Machine Learning (QML) models aimed at the application in the NISQ era. These algorithms employ jointly parameterized quantum Circuits (PQCs) and classical optimization techniques for finding optimal quantum circuits that have desirable properties from the point of a given application. VQAs require less training datasets compared to conventional D Learning models - it implies faster training time than its counterpart classical technique, whereas quantum machines also consume less electric power than supercomputers at the same time. VQAs are already applied to change detection, chlorophyll concentration estimation in water, and detecting clouds. It can be used to predict small, medium or major changes in marine ecosystems, opening scope for better understanding and preserving marine habitats.

2. Quantum for Advanced Machine Learning:

Quantum algorithms are revolutionizing machine learning approaches for climate modeling. By integrating physics laws and models with practical datasets and Quantum Machine Learning (QML) models, researchers can more accurately predict and analyze the impacts of climate change on marine habitats and wildlife.

For instance, this approach enables modelling rainfall-runoff models, which can be further extended for the prediction of flooding and drought analysis.

Relying on physics-based approaches, quantum algorithms can leverage the benefits of physical laws to solve complex Partial Differential Equations (PDEs) involved in computational fluid dynamics (CFDs). Quantum-assisted machine learning models, unlike conventional neural networks, can use QML models to handle climate-related challenges with accurate modeling.

Moreover, it can generate better prediction and projection probabilities for both current and future climate events affecting marine ecosystems.

This novel technique showcases the potential of quantum algorithms for advanced machine learning in the context of climate change detection. These approaches can provide critical insights into the behavior of marine life, enabling researchers to better protect our planet's fragile ecosystems.

Quantum for Climate Modeling:

Utilizing quantum algorithms and models for climate modeling presents a promising solution to the challenges posed by the large-scale and computationally intensive nature of climate modeling. Traditional climate modeling involves extensive data and hundreds of millions of grid cells, each with multiple associated variables, resulting in a complex and resource-intensive computational process.

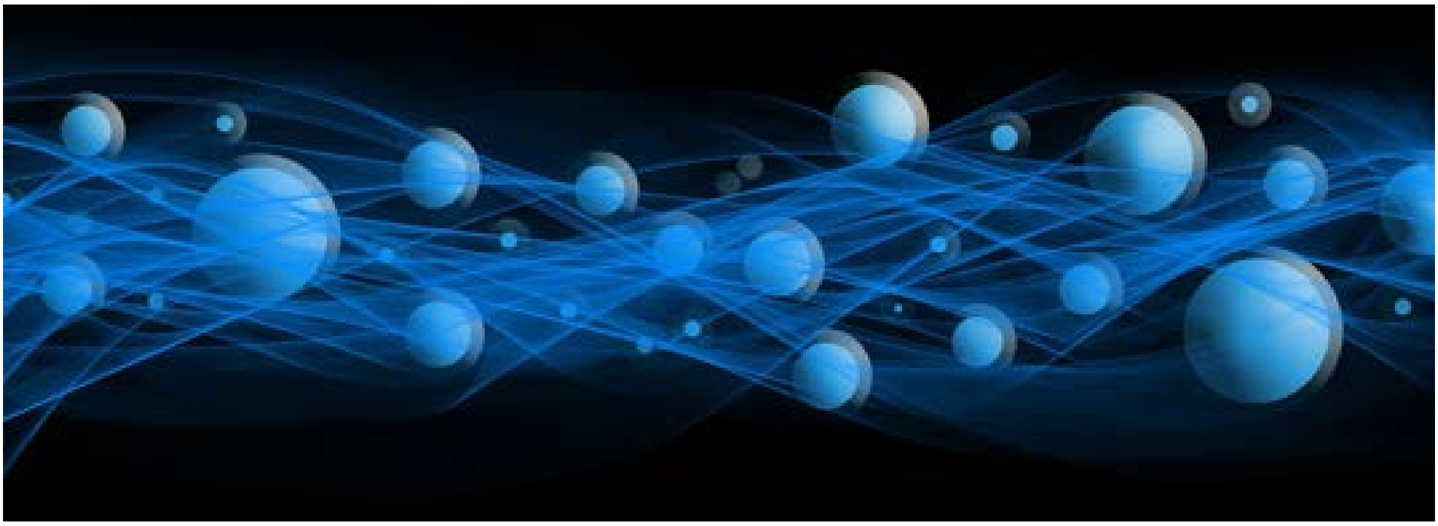
Quantum algorithms, leveraging principles of quantum information science, offer the potential to significantly enhance computational speed for these complex problems. They can transform climate models into linear equations, reducing the computational resources required and expediting the overall process. As a result, quantum algorithms can offer solutions to computationally expensive climate modeling and climate Partial Differential Equations (PDEs).

Several effective approaches can be employed:

- Variational Quantum Algorithms (VQAs) demonstrate increased expressive power compared to their classical counterparts, making them suitable for testing and solving climate PDEs.
- To address limitations in memory capacity and large-scale climate datasets, Quantum-based Neural Networks (QPINNs) can be utilized to predict and project climate states, particularly where conventional deep learning (DL) models struggle to generalize well with smaller datasets.
- Climate Quantum Machine Learning (QML) models offer a promising approach to maintain accuracy while reducing the spatial resolution of grid cells, enabling interpolation similar to conventional classical methods.
- Quantum machines can be leveraged to simulate atmospheric chemistry, providing fast and highly accurate methods for these simulations, which are crucial as the complexity of reaction pathways increases with the size of the molecules involved.

These quantum-assisted approaches demonstrate the potential to revolutionize climate modeling, offering efficient and accurate solutions to critical climate-related challenges.

Quantum Simulation Use Cases



Quantum Algorithm for Submarine Tephra Dispersal:

When a submarine volcano erupts, the hot gases and ash produce tephra, which is then dispersed through advection. This means that the tephra is carried by the movement of fluids, such as air or water, in a semi-infinite horizontal buoyant region. The buoyant region refers to the area where these fluids rise due to their lower density.

The horizontal aspect means that the tephra is moving in a direction perpendicular to the vertical direction of the buoyant region. In summary, this phrase describes how the tephra from a submarine volcanic eruption is dispersed by the movement of fluids in a certain region.

The study of tephra dispersal through advection in the semi-infinite horizontal buoyant region of a submarine volcanic eruption is important for marine life for several reasons:

- **Impact on marine ecosystems:** Tephra deposition and associated changes in water chemistry can affect the health and biodiversity of marine ecosystems, potentially disrupting the food chain and harming marine organisms.
- **Navigation and safety:** Understanding tephra dispersal is crucial for maritime navigation and the safety of ships, as accumulation of tephra can pose hazards to vessels and marine infrastructure.
- **Environmental monitoring:** Monitoring tephra dispersal provides insights into the environmental impact of submarine volcanic eruptions, allowing for better assessment and management of potential risks to marine life and coastal communities.
- **Fisheries and aquaculture:** Tephra deposition can influence water quality and nutrient levels, affecting the productivity of fisheries and aquaculture operations, making it important for assessing and mitigating potential impacts.

This is a perfect use-case where an efficient partial differential equation (PDE) solver uses principles of quantum information science to help study volcanic eruptions to improve marine lives. In engineering, Multiphysics processes are often represented using differential equations, therefore, efficient solvers can enhance the efficiency of computation processes by reducing the time, and complexities involved in the process.

Based on that, one such problem is the solution of viscous fluid flow governed by the Navier–Stokes equations. These equations universally represent scenarios ranging from turbulence in aerospace design in engineering to magneto-hydrodynamics in plasma physics. Hence, it is interesting though that these PDEs have only recently been attempted to be solved using quantum algorithms such as lattice models or some other quantum simulation methods.

Efficient classical-quantum hybrid algorithms developed by BosonQ Psi have successfully solved differential equations such as the Navier stokes equation, heat dissipation equations representing airflow, and heat flow. BosonQ Psi has achieved computational efficiencies during computation processes compared to other classical approaches. Therefore, solving complex differential equations for volcanic eruptions can help predict the impact on marine lives.

For example, in one of the use-cases, BQP's algorithm has shown significant improvements in simulation using Quantum Linear Solver Algorithms (QLSA) and variational algorithms suitable on High-Performance Computers (HPC). Additionally, it has reduced the number of computing resources and efficiently solves highly complex simulations.

Ocean Climate with Quantum (ClimateDT):

Figure: Digital twins of the Earth attempt to replicate the behavior of certain aspects of the planet based on Earth Observation data and physical models.

A precise digital model of the Earth's oceanic climate activity can forecast and evaluate the impacts of human-made or natural oceanic activities, offering opportunities to study their effects on marine life. Quantum algorithms and quantum computers are ideal candidates for creating an accurate ocean model due to the large volume of data needed.

To monitor and simulate interactions between the environment and human activities with high precision, quantum algorithms can be used to build digital twins. This enables the study of how natural phenomena and human actions influence the climate, moving towards comprehensive risk assessments from local climate plausibility evaluations.

Limitations of Current Climate Models

Cloud feedback and cloud-aerosol interactions significantly impact the equilibrium climate sensitivity range. Previous models inadequately represented clouds in Earth System Models (ESMs) due to the complexities of cloud formation and limitations in computational scale.

Recent advancements in cloud modeling have shifted towards probabilistic approaches in small-scale simulations. Accuracy can be enhanced through classical supercomputing and eventual quantum-accelerated HPC integration.

Quantum Approaches for ClimateDT

Key challenges include the quantum computer compatibility with "Big data" problems inherent in climate models.

Quantum computers excel in solving complex equations efficiently with a moderate amount of input and output variables, leveraging quantum parallelism.

For quantum computing to surpass classical methods, algorithms must be deep and encompass a high number of basic operations.

The advantage of quantum computing lies in tackling problems from innovative perspectives, especially in Computational Fluid Dynamics (CFD) or Partial Differential Equations (PDEs) processing. Quantum algorithms like the HHL algorithm and QSVT can accelerate CFD simulations by efficiently solving linear systems of equations without relying on conventional matrix inversion methods.

Leveraging hybrid classical/quantum algorithms for the NISQ era allows for fault-tolerant quantum computing advancements in oceanic climate modeling, paving the way for more efficient and accurate modeling techniques.

Business Opportunity

The Maritime Freight Transport Market size is estimated at USD 381.69 billion in 2024, and is expected to reach USD 471.81 billion by 2029, growing at a CAGR of 4.33% during the forecast period (2024-2029).The maritime freight transport industry is responsible for the carriage of around 90% of world trade. Seaborne trade continues to expand, bringing benefits for consumers across the world through competitive freight costs. Thanks to the growing efficiency of shipping as a mode of transport and increased economic liberalization, the prospects for the industry's further growth continue to be strong.

The global marine biotechnology market size was reached at USD 5.9 billion in 2022 and it is projected to hit around USD 11.7 billion by 2032 and anticipated to increase at a CAGR of 7.09% during the forecast period from 2023 to 2032.

The environment, conservation and wildlife organizations market size has grown strongly in recent years. It will grow from $26.22 billion in 2023 to $28.16 billion in 2024 at a compound annual growth rate (CAGR) of 7.4%.

The growth in the historic period can be attributed to environmental awareness, advocacy and education, conservation projects, legal advocacy.

The environment, conservation and wildlife organizations market size is expected to see strong growth in the next few years. It will grow to $36.65 billion in 2028 at a compound annual growth rate (CAGR) of 6.8%. The growth in the forecast period can be attributed to climate change mitigation, sustainable practices, renewable energy and green technology, marine conservation. Major trends in the forecast period include climate change mitigation, biodiversity conservation, sustainable agriculture and food systems, green finance and impact investing, eco-friendly technology.

The Global Ocean-Based Climate Solutions Market size was valued at USD 10.2 Bn in 2022 and is expected to reach USD 29.71 Bn by 2029, at a CAGR of 16.5%.

The global quantum computing market size is projected to grow from $1,160.1 million in 2024 to $12,620.7 million by 2032, at a CAGR of 34.8%.

Other Opportunities:

Coastal Infrastructure Development: Quantum climate models can inform coastal infrastructure projects by predicting sea level rise, storm surge patterns, and potential erosion risks.

Marine Pollution Mitigation: By pinpointing areas vulnerable to pollution dispersion, governments and environmental agencies can develop targeted strategies to protect sensitive ecosystems.

Carbon Capture and Storage: Quantum simulations can help optimize the placement and operation of carbon capture facilities, leading to more effective strategies for mitigating climate change.

About Artificial Brain

Artificial Brain is a quantum computing software company developing optimization solutions for Aerospace, Energy, and Defense. Artificial Brain has a global presence with offices in the USA, Netherlands, and India and ability to tap into diverse markets, talents, and resources.

Artificial Brain also emerged as one of winners of the Prototype Track in the Deep Tech Category of the highly regarded myEUspace competition, organized by the European Union Agency for the Space Programme (EUSPA).

Artificial Brain's innovative quantum algorithm, designed to optimize real-time scheduling for multiple Earth Observation Satellites (EOS), clinched the victory, promising to bring groundbreaking solutions in the integration of EU space data with cutting-edge technologies like Artificial Intelligence (AI) and Quantum Computing.

Furthermore, their contributions to sustainability challenges have been featured in Nature India, underscoring their commitment to leveraging quantum based technologies for global sustainability.

Website: www.artificialbrain.us

About BQP

BosonQ Psi (BQP) is a SaaS simulation software startup leveraging Quantum algorithms that accelerate advanced simulations to design high-quality products faster and more economically. Its product, BQPhy®, is integrated with Quantum algorithms which can overcome simulations which complex, expensive, and time-consuming for customers from mobility, energy, construction, and biotech sectors. BQP currently brings state-of-the-art simulation capabilities integrated with Quantum-inspired algorithms, which can run on today's HPC (High Performance Computing) and provide near-term value.

It is also working on hybrid-classical algorithms for future simulation capabilities. The company is part of startup programs by IBM, Intel, AWS (Amazon Web Services), Microsoft, TCS (Tata Consulting Service), and Tech Mahindra. It has raised over a million dollars from investors and government grants. It is part of Alchemist Accelerator, Hustle Defense Accelerator program by Griffiss Institute, and UK Innovate's net zero program among others. BQP actively partners with research and academic institutions to produce white papers and disseminate knowledge on engineering simulations and quantum computing, focusing on innovative solutions for sustainability challenges.

Website: www.bosonqpsi.com

About Quantum Inspire

Quantum Inspire is Europe's first quantum system that is accessible for public use. A world's first is that Quantum Inspire connects to two different kinds of quantum processors: spin qubits and superconducting transmon qubits, allowing users to compare both types of quantum processors. It also integrates different programming languages, allowing users to compare how languages affect simulations. Quantum Inspire (QI) is initiated by QuTech the advanced research center for quantum computing and quantum internet founded by TU Delft and TNO.

Website: www.quantum-inspire.com

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