

# AI and Quantum Algorithmics

## Optimisation Tools for Product Engineering

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### ***I. Foundations of Optimisation in Product Engineering***

#### **Part A**

Hello, my name is Nezar ALI and I will introduce the foundations of optimisation in product engineering.

Product engineering is, at its core, an optimisation problem. Engineers are constantly required to make decisions under multiple, often conflicting constraints: performance versus cost, weight versus strength, efficiency versus reliability, or innovation versus manufacturability. These decisions are rarely isolated; they are interconnected across the entire product lifecycle, from conceptual design to production and end-of-life considerations.

Classical engineering design theory formalizes this process as an iterative loop of synthesis, analysis, and evaluation. In their seminal work, Pahl and Beitz describe engineering design as a systematic exploration of solution spaces guided by objectives and constraints rather than a purely intuitive process (PAHL G. and BEITZ W., *Engineering Design*, Springer Verlag, London, 1988). Optimisation is therefore not an optional step, but a structural component of engineering methodology.

However, over the past decades, the nature of engineering problems has changed dramatically. Modern products integrate mechanical structures, electronics, embedded software, and complex supply chains. This leads to extremely large design spaces, often combinatorial in nature, where the number of possible solutions grows exponentially with the number of design variables. In such contexts, exhaustive search is impossible, and even advanced numerical optimisation techniques can become computationally prohibitive.

#### **Part B**

Hello, my name is Gabriel Conte and I will explain how we can overcome those limitations using modern technology.

To cope with this complexity, engineers have increasingly turned to Artificial Intelligence. Machine learning methods allow the use of data to approximate simulations, guide exploration, and support decision-making. Yet, even AI-based optimisation remains constrained by classical computational limits, particularly for discrete and highly constrained problems.

This observation motivates the exploration of new computational paradigms. Quantum computing, and more specifically quantum algorithmics for optimisation, offers alternative ways of exploring large solution spaces. While quantum computers are not universally faster, they show strong potential for specific classes of optimisation problems that are central to product engineering.

In this podcast, we will examine how **Artificial Intelligence and quantum algorithmics**, taken together, can be understood as **complementary optimisation tools**, and how their combination may reshape the future of engineering design.

## ***II. La inteligencia artificial como motor de optimización en la ingeniería de productos***

### **Part A**

Hola, me llamo Paul RAYSSAC, y en esta parte voy a centrarme en el papel de la inteligencia artificial en la optimización de la ingeniería de productos.

En las últimas décadas, la inteligencia artificial se ha consolidado como una herramienta central para la optimización en ingeniería. Su adopción responde a una necesidad clara: reducir el coste computacional del diseño y mejorar la calidad de las decisiones en contextos de alta complejidad. En particular, los métodos de aprendizaje automático permiten tratar problemas donde los enfoques analíticos clásicos resultan insuficientes.

Una de las aplicaciones más importantes de la IA en ingeniería de productos es la creación de *modelos sustitutos*, o *surrogate models*. Estos modelos aproximan simulaciones físicas costosas, como análisis por elementos finitos o simulaciones

térmicas— a partir de datos previamente calculados. De este modo, es posible acelerar significativamente los ciclos de optimización y explorar un mayor número de soluciones potenciales.

La IA también desempeña un papel clave en la optimización multiobjetivo. Muchos problemas de diseño implican compromisos entre criterios contradictorios, como peso, coste, resistencia o impacto ambiental. Algoritmos evolutivos, redes neuronales y métodos bayesianos permiten identificar fronteras de Pareto y ayudar al ingeniero a tomar decisiones informadas, no únicamente numéricamente óptimas.

## **Part B**

Hola, me llamo Thomas CLAVERIE, y en esta parte explicaré cómo la inteligencia artificial aborda problemas de decisión en ingeniería y cuáles son sus principales limitaciones.

Otro enfoque relevante es el aprendizaje por refuerzo, que resulta especialmente adecuado para problemas secuenciales, como la planificación de procesos de fabricación, la gestión del ciclo de vida del producto o la optimización de cadenas logísticas. En estos casos, el sistema aprende estrategias óptimas mediante interacción con un entorno simulado.

Sin embargo, a pesar de sus éxitos, la inteligencia artificial clásica sigue enfrentándose a limitaciones fundamentales. Muchos problemas industriales son de naturaleza combinatoria y pertenecen a clases de complejidad elevadas, donde incluso los métodos basados en IA requieren tiempos de cálculo prohibitivos.

Por este motivo, la investigación reciente propone combinar la inteligencia artificial con nuevos paradigmas computacionales. Como señala Kadowaki, la integración de IA con computación cuántica puede abrir nuevas vías para la automatización avanzada y la optimización en ingeniería (*Quantum Computing and AI: Perspectives on Advanced Automation in Science and Engineering*, arXiv, 2025). Esta transición marca el paso hacia enfoques híbridos, que serán el foco de las siguientes partes del podcast.

### ***III. Quantum Algorithmics for Engineering Optimisation Problems***

Hello, my name is Jokin SUARES and in this part I will introduce quantum algorithmics for optimisation.

Quantum computing introduces a radically different computational paradigm, based on quantum-mechanical principles such as superposition and entanglement. Unlike classical bits, quantum bits, or qubits, can represent multiple states simultaneously. This property makes quantum computing particularly interesting for optimisation problems involving very large combinatorial search spaces.

In product engineering, many optimisation problems are discrete by nature. Examples include selecting component configurations, determining material layouts, scheduling manufacturing operations, or designing modular architectures. These problems are often NP-hard, meaning that the number of possible solutions grows exponentially with problem size. Classical optimisation algorithms typically rely on heuristics to navigate these spaces, but they can easily become trapped in local optima.

One of the most prominent quantum optimisation methods is the **Quantum Approximate Optimization Algorithm**, or QAOA. Introduced by Farhi and collaborators, QAOA is a hybrid quantum–classical algorithm designed to solve combinatorial optimisation problems by encoding them into a quantum Hamiltonian and iteratively improving the solution through parameter optimisation (FARHI E. et al., “A Quantum Approximate Optimization Algorithm”, arXiv, 2014). QAOA is particularly attractive because it is compatible with near-term quantum hardware and naturally integrates classical optimisation loops.

Another important approach is **quantum annealing**, which is inspired by classical simulated annealing but exploits quantum tunnelling to escape local minima. Quantum annealing is well suited for problems formulated as Quadratic Unconstrained Binary Optimization, or QUBO models. Many engineering optimisation problems, including structural layout, scheduling, and process planning, can be expressed in this form.

However, it is important to stress that quantum algorithms are not universally superior to classical ones. Current quantum devices operate in the so-called NISQ era: they are noisy, limited in scale, and prone to errors. As a result, purely quantum solutions are rarely practical today.

Instead, quantum algorithmics should be viewed as a **specialised optimisation accelerator**, particularly effective when combined with classical methods. This perspective naturally leads to hybrid AI–quantum approaches, where artificial intelligence helps formulate, guide, and refine quantum optimisation, a topic that will be developed in the next part of this podcast.

#### ***IV. Enfoques híbridos IA–cuántica y casos de estudio en ingeniería***

Hola, me llamo Enzo DE ALMEIDA y en esta parte voy a presentar los enfoques híbridos entre inteligencia artificial y computación cuántica aplicados a la ingeniería.

Dadas las limitaciones actuales del hardware cuántico, la mayoría de las aplicaciones realistas en ingeniería no se basan en algoritmos puramente cuánticos, sino en enfoques híbridos que combinan computación clásica, inteligencia artificial y algoritmos cuánticos especializados. En estos sistemas, cada tecnología se utiliza allí donde resulta más eficiente.

Un primer papel clave de la inteligencia artificial en estos enfoques híbridos es la **formulación del problema**. Muchos problemas de ingeniería deben transformarse en modelos matemáticos específicos, como formulaciones QUBO, para poder resolverse mediante algoritmos cuánticos. La IA puede automatizar o asistir este proceso, identificando variables relevantes, restricciones y funciones objetivo a partir de datos de diseño.

Además, la IA se emplea para **guiar la optimización cuántica**. Por ejemplo, algoritmos de aprendizaje automático pueden ajustar los parámetros de algoritmos como QAOA, reduciendo el número de iteraciones necesarias y mejorando la calidad de las soluciones obtenidas en hardware real. Este enfoque resulta especialmente importante en la era NISQ, donde el tiempo de cálculo y el ruido son recursos críticos.

Estos métodos híbridos ya se han aplicado a diversos casos de estudio en ingeniería. En optimización topológica, la computación cuántica se ha utilizado para decidir la distribución discreta de material, mientras que métodos clásicos se encargan del análisis estructural. En ingeniería de materiales, algoritmos cuánticos han sido explorados para optimizar configuraciones de laminados compuestos, reduciendo peso sin comprometer resistencia.

Otro ejemplo relevante es la planificación industrial y la optimización de procesos de fabricación. Problemas como la disposición de fábricas, la planificación de operaciones o la secuencia de desensamblaje pueden formularse como problemas combinatorios donde los métodos cuánticos muestran un fuerte potencial.

Estos casos no indican una sustitución inmediata de los métodos clásicos, sino una **coexistencia estratégica**. La combinación de IA y computación cuántica permite abordar problemas que antes eran demasiado complejos o costosos computacionalmente. En este sentido, los enfoques híbridos representan una transición pragmática hacia la ingeniería del futuro.

## ***V. Future Perspectives: Toward Quantum-Enhanced Engineering Design***

Hello, my name is Eneko ARBLEBIDE and I will conclude this podcast by discussing future perspectives and implications for engineering.

The convergence of artificial intelligence and quantum algorithms represents more than a technological trend; it signals a methodological evolution in product engineering. Rather than replacing established engineering practices, these tools extend the engineer's capacity to explore, evaluate, and reason about increasingly complex design spaces.

In the short term, the most impactful applications are expected to remain hybrid. Artificial intelligence will continue to handle data-driven modeling, uncertainty management, and decision support, while quantum algorithms act as specialised accelerators for discrete and combinatorial optimisation problems. This division of roles reflects the current maturity of both technologies and aligns with the constraints of near-term quantum hardware.

From an industrial perspective, sectors such as aerospace, automotive engineering, and advanced manufacturing are particularly well positioned to benefit. Problems related to lightweight structural design, modular product architectures, logistics optimisation, and sustainable manufacturing already push the limits of classical computation. Early case studies suggest that AI–quantum approaches can deliver competitive solutions with reduced computational effort, even before full-scale quantum advantage is achieved.

In the longer term, as quantum hardware scales and becomes more reliable, we may observe deeper transformations. Engineering design could shift away from deterministic optimisation toward probabilistic and exploration-driven paradigms. Rather than identifying a single “optimal” solution, engineers may increasingly work with ensembles of high-quality solutions, supported by quantum-enhanced exploration and AI-based interpretation.

This evolution also has implications for engineering education and tools. Future engineers will need to understand not only physical models and numerical methods, but also how to formulate problems for AI systems and quantum algorithms. As emphasized by Kadowaki, the integration of these technologies points toward a new generation of computer-aided engineering systems (*Quantum Computing and AI: Perspectives on Advanced Automation in Science and Engineering*, arXiv, 2025).

In conclusion, artificial intelligence and quantum algorithmics should be seen as complementary optimisation tools that augment human expertise. Their combined use does not eliminate the role of the engineer; instead, it reshapes it. For product engineering, this convergence offers a credible pathway to addressing complexity at scales that were previously unreachable.