

Measurement of Complexity in Large Complex Projects ¹

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In the realm of project management, the measurement of complexity in large complex projects (LCPs) presents a significant challenge yet is essential for successful execution. Traditional measures of project complexity may fall short in capturing the intricate interdependencies, uncertainties, and dynamic nature of LCPs. However, a new perspective emerges from the world of quantum physics and relativistic theory, offering analogies that shed light on the behaviors observed in LCP performance.

This paper delves into the concept of Quantum Project Management², which draws inspiration from quantum and relativistic theories to redefine how we perceive and manage complexity in large complex projects. By exploring quantum analogies such as entanglement entropy, quantum circuit complexity, computational complexity, and quantum complexity classes, this document aims to provide project managers with a fresh lens through which to view and navigate the complexities of LCPs.

This paper explores the application of quantum concepts to LCPs, highlighting the interconnected nature of project elements, uncertainties, and emergent properties. By leveraging quantum analogies, project managers can gain valuable insights into the intricate relationships within LCPs and develop strategies to enhance project performance, adaptability, and innovation.

Join us on a journey through the quantum realm of project management as we explore the parallels between quantum phenomena and the complexities of large complex projects, paving the way for a new understanding of project management in the modern era.

Key points laid out in this paper include:

- Quantum analogies, such as entanglement entropy and quantum circuit complexity, offer a new perspective on understanding the interconnected nature of large complex projects (LCPs) and the challenges posed by uncertainties and emergent properties
- Computational complexity measures and quantum complexity classes provide tools for assessing and managing the computational resources and interdependencies within LCPs, enabling project managers to make informed decisions in the face of uncertainty

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² Prieto, R. (2024). Quantum Project Management, *PM World Journal*, Vol. XII, Issue I, January 2024. <https://peworldlibrary.net/wp-content/uploads/2024/01/pmwj137-Jan2024-Prieto-Quantum-Project-Management-.pdf>

- Quantum concepts like Quantum Fisher Information and Quantum Kolmogorov Complexity offer insights into the fragility of project plans and the intrinsic complexity of LCPs, leading to more adaptive and resilient project management strategies
- Quantum Project Management introduces new strategic decision-making approaches for LCPs, emphasizing the interconnectedness of project components, the nature of complexity classes, and the importance of modularization and precedence minimization
- By leveraging quantum analogies and measurement approaches, project managers can enhance their ability to navigate the complexities of LCPs, drive innovation, and achieve successful project outcomes in an ever-evolving landscape of large complex projects

Measuring Complexity

Measuring complexity in large complex projects today is challenging and necessary yet the range of measures explored may be self-limiting based on a more classical perspective of projects as bounded and decomposable. The author's recent paper on Quantum Project Management opens the aperture on consideration of the management of large complex projects (LCP). This paper draws by analogy from the world of relativistic theory (scale) and quantum theory (complexity) to describe the behaviors we observe in LCP performance and in the process open our thinking with respect to the limitations of classical project management theory.

This paper looks more closely at the measurement of complexity as described in "Quantum Project Management – Complex and Entangled" (6 of 10 in a series)³ where three measurement approaches are described, and those descriptions are not repeated here:

- CIFTER
- Analytic Hierarchy Process (AHP)
- Project Complexity and Risk Assessment Model (PCAM)

Specifically, complexity measurement in the context of quantum systems will be considered in this paper as an analog for complexity in LCP.

Complexity & Entanglement

In the realm of quantum physics, the analog for complexity is often described in terms of quantum entanglement and the intricate relationships between quantum particles. Complexity in quantum systems arises from the entangled states where the properties of one particle become interdependent with those of another, leading to a highly interconnected and nuanced

³ [\(PDF\) Quantum Project Management – Complex and Entangled \(researchgate.net\)](#)

structure. This complexity is challenging to describe classically and contributes to the unique behaviors observed at the quantum level.

In a quantum system, complexity often arises from the intricate interplay between multiple quantum states and their superposition, entanglement, and interference effects. These phenomena can give rise to non-intuitive behaviors and computational challenges that are fundamentally different from classical systems. Complexity in quantum systems can be described in terms of the number of quantum states involved, the degree of entanglement between these states, and the difficulty in predicting and controlling their behavior due to the inherent uncertainty dictated by quantum mechanics.

We witness this entanglement throughout large complex projects and have previously described one aspect of this, namely, coupling⁴.

Measuring complexity in quantum systems is a challenging task due to the non-intuitive nature of quantum mechanics and the richness of quantum phenomena. However, several metrics have been proposed to quantify the complexity of quantum systems and warrant consideration in the context of LCP. Some of these metrics include:

- **Entanglement entropy:** This measures the amount of entanglement between different parts of a quantum system. It quantifies the degree to which the state of one part of the system is dependent on the state of another part. This is a significant consideration in LCP performance especially with respect to the presence of significant and often unnecessary precedences.
- **Quantum circuit complexity:** This metric quantifies the complexity of quantum circuits required to prepare a given quantum state from a simple initial state. It is often measured in terms of the number of quantum gates, or the depth of the circuit required. This can be thought of as the number of transformational processes and steps required in LCP as well as the “length” of the critical path or other activity chains.
- **Computational complexity:** This measures the computational resources, such as time and space, required to simulate or compute properties of the quantum system using classical or quantum algorithms. The degree of difficulty in simulating an LCP project execution approach is one measure, albeit indirect, of LCP complexity.
- **Quantum Kolmogorov complexity:** This measures the shortest description length of a quantum state or process, which captures its intrinsic complexity. In the context of an LCP consider how hard it is to describe its inherent complexity or the desired outcomes of the project.

⁴ Prieto, R. (2020). Coupling in Large Complex Projects, National Academy of Construction Executive Insight ([PDF](#)) [Large Complex Projects Coupling in Large Complex Projects Key Points \(researchgate.net\)](#)

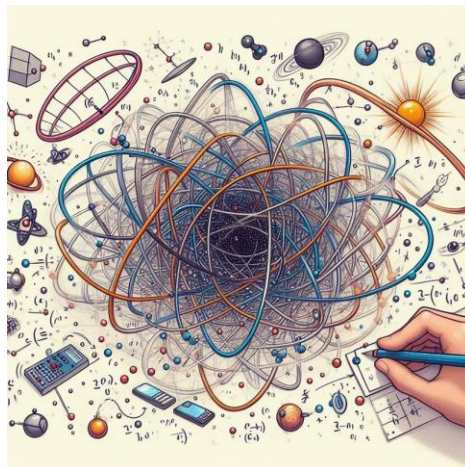
- **Quantum Fisher information:** This measures the sensitivity of a quantum state to small perturbations⁵, providing insights into the complexity of quantum states with respect to quantum metrology and information processing tasks. This is analogous to assessing the fragility of LCP execution plans.

These metrics have been proposed and studied in various contexts, including quantum information theory, quantum computation, quantum field theory, and quantum chaos. However, each metric captures different aspects of complexity in quantum systems, and there is ongoing research to understand the relationships between them and their implications for quantum technologies and fundamental physics.

Each of these measures of complexity are looked at in more detail in the following sections with an eye towards identifying potential application to the measure of LCP complexity in the context of the broader theory of Quantum Project Management.

Entanglement Entropy

Entanglement entropy is a concept from quantum information theory that quantifies the amount of entanglement between subsystems of a larger quantum system. It provides insights into the complexity and correlations present in quantum states. This would be analogous to sub-projects in a LCP or discrete project within a major program.



⁵ Consideration of perturbations also benefits from consideration of the behaviors of other complex systems especially when modularity or the use of modules in the system is considered. The relationship between complexity and modularity of “systems” mirrors that of nature, where complex systems reward modularity and its ability to limit the effects of perturbations while at the same time recognizing that excessive modularity exposes the system negatively to the effects of even stronger, more systemic perturbations. The same is true for large complex projects. See “Coupling in Large Complex Projects” for a description of the relationship between modularity and complexity.

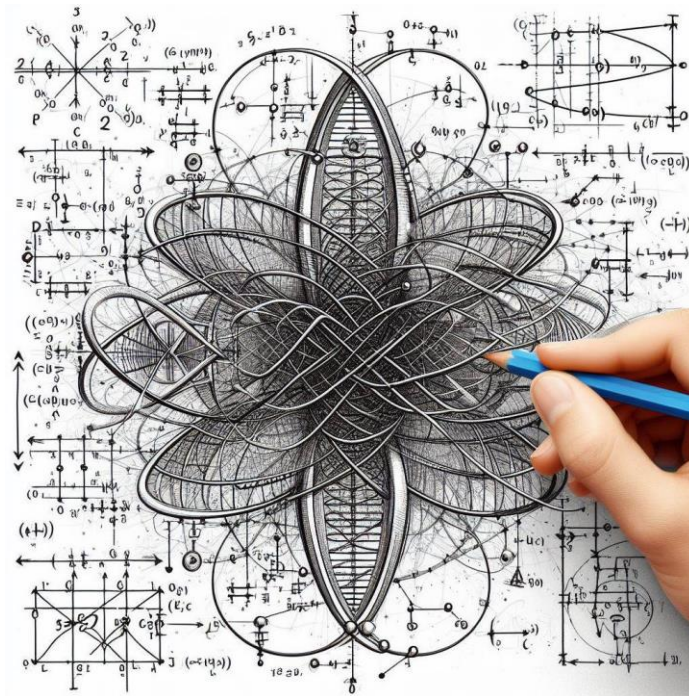
Entanglement entropy and how it is calculated can be described as follows:

- **Quantum System:** In quantum physics we consider a composite quantum system composed of multiple subsystems, such as qubits in a quantum register or particles in a quantum many-body system. In projects these subsystem would be discrete and identifiable elements of the project. Returning to the physics analog, the system can be described by a joint quantum state representing the entire system.
- **Subsystem Division:** Entanglement entropy focuses on the entanglement between two or more subsystems obtained by dividing the larger quantum system. The division can be arbitrary but is often chosen based on physical considerations or the structure of the system. This analogy maps well to LCP especially those making extensive use of modules⁶.
- **Density Matrix:** The density matrix of the entire system is used to describe its quantum state. The density matrix captures both the pure and mixed nature of the quantum state, allowing for the representation of statistical mixtures of quantum states. Mixed states arise in quantum mechanics in two different situations:
 - When the preparation of the system is not fully known, and thus one must deal with a statistical ensemble of possible preparations. In LCP this can be a characteristic of poorly founded projects.
 - When one wants to describe a physical system that is entangled with another, without describing their combined state; this case is typical for a system interacting with some environment (e.g., decoherence). We see this entanglement with LCP and their interaction with the broader ecosystem they are part of. If decoherence has occurred the system (project) behaves as a classical statistical ensemble of the different elements rather than as a single coherent quantum superposition of them, the true value point from a systems perspective.
- **Reduced Density Matrix:** To analyze the entanglement between subsystems, one constructs the reduced density matrix for each subsystem by tracing out the degrees of freedom of the other subsystems. For a bipartite system composed of subsystems “A” and “B,” the reduced density matrix for subsystem “A” is obtained by tracing out the degrees of freedom associated with the subsystem. It allows us to study each subsystem separately.

⁶ Prieto, R. (2017) Complexity in Large Engineering & Construction Programs; PM World Journal Vol. VI, Issue XI – November 2017

Quantum Circuit Complexity

Quantum circuit complexity refers to the measure of how "complicated" or "sophisticated" a quantum circuit is, often quantified in terms of the number of quantum gates or the depth of the circuit. It reflects the resources required to implement a particular quantum computation.



Here is a more detailed description of quantum circuit complexity and how it is calculated:

- Quantum Circuit:** A quantum circuit is a sequence of quantum gates applied to an initial quantum state. These gates represent quantum operations that manipulate the quantum bits (qubits) in the circuit. A simple gate would be one where a consistent, defined action occurs at the gate in a linear fashion. In a project context the gate describes the classical transformation process of a decomposed project. More complex gates exist and introduce entanglement and therefore complexity into our project system.
- Quantum Gates:** Quantum gates are basic building blocks of quantum circuits. They perform operations such as unitary transformations, measurements, or entanglement operations on qubits. Common quantum gates include Hadamard gate, Pauli gates, CNOT gate, and phase gates.

- **Hadamard gate:** Creates an equal superposition state. In LCP a given gate/task can either succeed or fail.
 - **Pauli gates:** Quantum equivalent of the NOT gate for classical computers.
 - **CNOT gate:** Controls a gate action based on the state of one of the inputs, allowing the second input to either proceed through the gate or not. It can be used to manage superposition states. If the requisite precedences are not in place a given task or chain of tasks cannot proceed in an LCP. Think of these as approvals, availability of the means and methods of construction, or other items external to the task at hand.
 - **Phase gates:** Probabilities are unchanged, but a phase shift helps model complex quantum interactions and study physical phenomena. It facilitates understanding of quantum aspects of project execution plans.
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- **Depth of the Circuit:** The depth of a quantum circuit refers to the length of the longest path from the input qubits to the output qubits in the circuit, measured in terms of the number of gates along that path. A deeper circuit implies more sequential operations and often indicates higher computational complexity. In LCP this can be thought of as analogous to the “length” of the critical path, i.e., the number of sequential gates/tasks that lie along it. Consideration should also be given to other near critical path chains of activities which may become governing under certain situations⁷.
 - **Number of Gates:** Quantum circuit complexity can also be measured by the total number of quantum gates used in the circuit. This metric captures the overall complexity of the computation and the amount of physical resources needed to implement the circuit. This is analogous to what we see in LCP with 100,000 or more Work Breakdown Structure (WBS) elements.
 - **Gate Set:** The choice of quantum gates used in the circuit affects its complexity. Different gate sets may have different computational capabilities and may require different resources for implementation. LCP means and methods choices and their linkage to the overall project execution plan, shared resource requirements and degree of difficulty are analogous. A preponderance of gates/tasks reliant on or influenced by “conditions precedent” also impact complexity.
 - **Input Parameters:** The input parameters for calculating quantum circuit complexity typically include:
 - **Number of qubits:** The number of qubits in the quantum circuit. (Quantum mechanics allows the qubit to be in a coherent superposition of multiple states

⁷ Prieto, R. (2017) Complexity in Large Engineering & Construction Programs; PM World Journal Vol. VI, Issue XI – November 2017

simultaneously, a property that is fundamental to quantum mechanics and quantum computing.)

- **Type and number of gates:** The types and total number of quantum gates used in the circuit. This is analogous to task types and number of both sequential and total tasks.
 - **Circuit topology:** The arrangement and connectivity of qubits and gates in the circuit. Analogous to the project execution plan for LCP.
 - **Quantum algorithm:** The specific quantum algorithm being implemented by the circuit, which influences the choice and arrangement of gates. For LCP this relates to the project's SBOs and recognizes the primacy of the scope baseline⁸.
- **Quantum Complexity Classes:** Quantum circuit complexity can also be related to complexity classes in quantum computation theory. Classes of complexity for LCP can also be defined and relate to the nature and extent of coupling within the project network.
 - **Calculation of Complexity:** Calculating the complexity of a quantum circuit involves analyzing its structure, gate composition, and depth. This analysis can be performed analytically or numerically, depending on the complexity of the circuit and the computational resources available. Similar approaches are possible for LCP. Three are described in "Quantum Project Management – Complex and Entangled."⁹ Quantum project management opens the aperture to consider additional measures of complexity calculation.

In summary, quantum circuit complexity measures the resources required to implement a quantum computation and is often quantified by the depth of the circuit or the number of quantum gates used. It plays a crucial role in understanding the efficiency and scalability of quantum algorithms and their implementation on quantum hardware. Similar insights can be gained with respect to LCP, providing guidance on practical decisions such as nature and degree of modularization to be considered; any requisite decoupling of activities through precedence minimization; and any scaling limitations associated with means and methods.

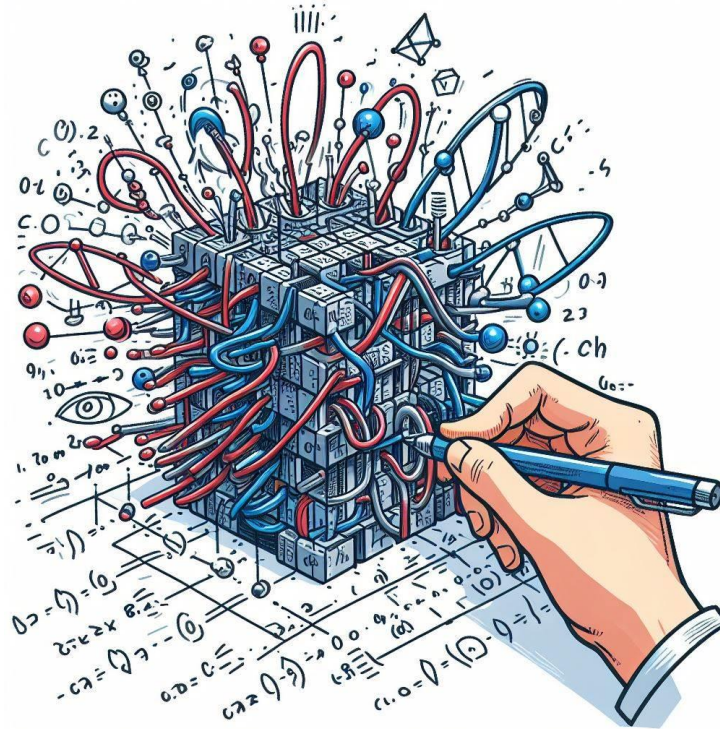
Computational Complexity

Computational complexity refers to the study of the resources, such as time and space, required to solve computational problems using algorithms. It provides a framework for understanding

⁸ Prieto, R. (2019). The Primacy of the Scope Baseline in Engineering & Construction Projects; *PM World Journal*, Vol. VIII, Issue IX, October 2019

⁹ [\(PDF\) Quantum Project Management – Complex and Entangled \(researchgate.net\)](#)

the efficiency and scalability of algorithms in solving problems of varying sizes. Computational complexity theory classifies problems into complexity classes based on the resources required by the most efficient algorithms to solve them.



Similarly, LCP complexity can be categorized into classes, potentially improving our understanding of likely LCP schedule and cost performance. Work remains to be done in defining LCP complexity classes, but key considerations should include:

- Number of inputs and outputs as well as the number of gates/tasks and number or couplings between tasks recognizing that some tasks may be coupled to more than one other task. This can be done by activity chain or holistically for the entire LCP. These considerations provide a first order measure of apparent complexity and facilitate comparison of alternative execution strategies. An apparent complexity index can be constructed¹⁰.
- Assessment of second and third order couplings which are not readily apparent from a review of the project execution plan and network. In effect the number of couplings

¹⁰ Prieto, R. (2017) Complexity in Large Engineering & Construction Programs; PM World Journal Vol. VI, Issue XI – November 2017

grows while the number of discrete nodes remains largely unchanged, concomitantly, complexity grows. This allows for a first order assessment of likely actual complexity¹¹.

- Uncertainty assessment, considered here as the ratio of actual to apparent complexity. This provides an additional measure of project performance uncertainty as we manage based on the defined project execution network but face risks from yet undiscovered hidden couplings or out of network perturbations.

Returning now to the quantum world, here is a description of computational complexity and how it is calculated:

- **Problem Instance:** Computational complexity theory starts with defining computational problems, which are abstract questions about some input data. For example, sorting a list of numbers or finding the shortest path in a graph are computational problems. The problem instance in quantum complexity theory refers to a specific input configuration for a quantum algorithm. For instance, if we are solving a quantum optimization problem, the problem instance would be a particular set of parameters or constraints.

Analogously, consider a quantum system as a large-scale construction project. The problem instance here could be a specific design blueprint, including architectural plans, material specifications, and project requirements. Alternately, the specific problem instance could be the design phase for a particular bridge span, considering load-bearing capacity, environmental factors, and aesthetic requirements.

- **Input Size:** The input size of a computational problem is typically measured in terms of the number of bits needed to represent the input data. For example, in the case of sorting algorithms, the input size could be the number of elements in the list to be sorted. In construction, the input size corresponds to the scale and scope of the project. It encompasses various factors:
 - **Project Scope:** The extent of work involved, such as the number of buildings, floors, rooms, and infrastructure components.
 - **Spatial Dimensions:** The physical dimensions—length, width, height—of structures being built.
 - **Materials:** The quantity and variety of materials required (e.g., concrete, steel, glass).
 - **Design Complexity:** The intricacy of architectural and engineering details.
 - **Environmental Factors:** Considerations related to local climate, soil conditions, and seismic risks.

¹¹ Ibid.

- **Regulatory Requirements:** Compliance with building codes, safety standards, and environmental regulations.
- **Stakeholder Interactions:** The number of parties involved—owners, contractors, subcontractors, and government agencies.
- **Algorithm:** An algorithm is a step-by-step procedure for solving a computational problem. Different algorithms may solve the same problem, but they may have different resource requirements. In quantum computation, an algorithm refers to a set of instructions or procedures that manipulate quantum states (represented by qubits) to solve specific problems. Quantum algorithms exploit quantum properties (such as superposition and entanglement) to perform tasks more efficiently than classical algorithms.

In construction, an algorithm corresponds to a systematic approach for organizing tasks, resources, and schedules. It involves sequencing activities, allocating resources (labor, machinery), and optimizing time and cost parameters. Examples include critical path method (CPM), genetic algorithms (GA) for schedule optimization, and machine learning-based algorithms for resource allocation.

- **Example Scenario:**
 - **Critical Path Method (CPM):**
 - **Algorithm:** CPM identifies the longest sequence of dependent tasks (critical path) that determine the project duration.
 - **Construction Analogy:** Think of CPM as the “quantum circuit” of a construction project. It orchestrates activities, ensuring smooth flow and timely completion.
 - **Measurement:** Tracking progress along the critical path mirrors quantum measurements collapsing superpositions.

Remember, both quantum systems and construction projects involve intricate interplay, problem solving, and trade-offs. While quantum complexity explores the limits of computation, construction complexity shapes our physical world.

- **Resource Measure:** The primary resources considered in computational complexity theory are time and space. Time complexity measures the number of computational steps (or operations) performed by an algorithm as a function of the input size. Space complexity measures the amount of memory (or storage) required by the algorithm to solve the problem. These measures help us understand the cost of running quantum algorithms and guide efficient resource allocation. Examples include the number of qubits required for a specific computation or the depth of quantum circuits.

Imagine a construction project as a quantum system. Just as quantum algorithms require specific resources, construction projects need various resources to succeed. The resource measures in construction correspond to quantifying the availability and utilization of critical project components. In construction, resource measures assess the availability and efficiency of critical elements:

- **Labor:** The workforce—skilled workers, engineers, project managers.
- **Materials:** Raw materials (wood, cement, steel) and equipment (bulldozers, cranes).
- **Time:** Project duration and scheduling.
- **Budget:** Financial resources allocated for the project.

These measures guide decision-making, optimize resource allocation, and minimize waste.

- **Worst-case Analysis:** Computational complexity often focuses on worst-case analysis, which provides an upper bound on the resources required by an algorithm to solve a problem for any input instance of a given size. In quantum computation, worst-case analysis assesses the performance of quantum algorithms under the most unfavorable input conditions. It focuses on scenarios where the input data or problem instance leads to the maximum computational effort or resource usage. For example, in quantum approximate optimization algorithms (QAOA), worst-case analysis considers the most challenging instances for optimization problems.

Imagine a large construction project as a quantum system. Just as quantum algorithms face worst-case scenarios, construction projects encounter challenging conditions. The worst-case analysis in construction corresponds to evaluating project risks and resource constraints under *extreme* circumstances. In construction, worst-case analysis involves assessing potential risks and delays that could significantly impact project outcomes. It considers scenarios such as:

- **Budget Overruns:** What if unexpected costs arise due to material shortages or design changes?
- **Time Delays:** What if adverse weather conditions or labor strikes disrupt the construction schedule?
- **Resource Shortages:** What if critical resources (skilled workers, equipment) become scarce?

The goal is to prepare for these worst-case scenarios and develop contingency plans. Caution is urged, for all too often we shape our evaluations by optimism bias and a

predisposition to normal distributions. Large complex projects live in a world of fat tails¹² driven by complexity, uncertainty and emergence.

- **Complexity Classes:** Problems are classified into complexity classes based on the resources required by the most efficient algorithms to solve them. Complexity classes in the context of LCP was previously discussed.
- **Calculating Complexity:** To calculate the computational complexity of an algorithm, one typically analyzes its behavior as a function of the input size. For example, one might analyze the number of comparisons performed by a sorting algorithm or the number of iterations in a search algorithm. This analysis helps determine the algorithm's time complexity and space complexity.

Time complexity refers to the effort required by an algorithm to execute as a function of the input size. In quantum computing, we analyze how the number of quantum gates (operations) scales with the problem size. Quantum algorithms may exhibit different time complexities compared to classical algorithms. In LCP we see non-linear scaling of time with LCP size (and complexity). In part this is reflected in the all too often schedule overruns we see.

Space complexity assesses the memory resources (quantum registers or qubits) needed during computation. In quantum systems, space complexity relates to the number of qubits required to represent and manipulate quantum states. It impacts the overall memory usage. Therefore, it should not come as a surprise that quantum simulations of physical systems often demand a large number of qubits to accurately model complex interactions.

Algorithms can optimize either time or space (required resources). Some quantum algorithms trade time complexity for reduced space (resource) requirements. Quantum computers have limited qubits, imposing constraints on both time and space complexity. Time and resources are similarly constrained in LCP. Balancing these factors is crucial.

Understanding time and space complexity helps us design efficient quantum algorithms and manage resource allocation effectively in LCP.

- **Asymptotic Analysis:** In many cases, computational complexity analysis focuses on asymptotic behavior, where the resource requirements are analyzed as the input size

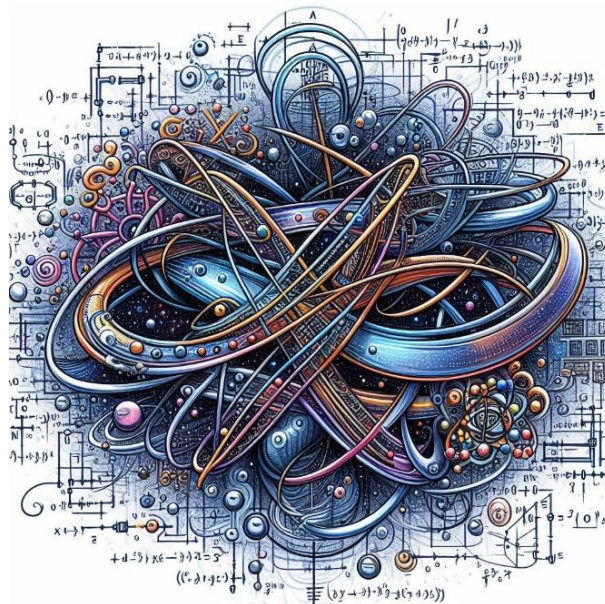
¹² Prieto, R. (2018) Fat Tails National Academy of Construction Executive Insights ([PDF](#)) [Risk and Opportunities Fat Tails Key Points](#) ([researchgate.net](https://www.researchgate.net))

approaches infinity. This allows for generalization and comparison of algorithms across different problem sizes. Stress testing project execution plans by alternately assuming some resources to be abundant and readily available and alternately, absent or highly constrained, helps build resilience into project execution approaches.

In summary, computational complexity provides a framework for understanding the efficiency and scalability of algorithms in solving computational problems. It involves analyzing the resources required by algorithms as a function of the input size and classifying problems into complexity classes based on their resource requirements. The calculation of computational complexity involves analyzing the behavior of algorithms with respect to time and space usage.

Quantum Kolmogorov complexity

Quantum Kolmogorov complexity is a measure of the shortest description length of a quantum state or process. It quantifies the amount of information needed to specify the state or process, independent of the algorithm or computational model used to generate it. Unlike classical Kolmogorov complexity, which deals with classical strings of bits, Quantum Kolmogorov complexity extends the notion to quantum states and processes.



Here is a more detailed description of Quantum Kolmogorov complexity and how it is conceptualized:

- **Quantum State or Process:** Quantum Kolmogorov complexity deals with quantum states or processes, which can be represented by density matrices or unitary operators, respectively.
- **Description Length:** The description length refers to the length of the shortest classical description needed to specify the quantum state or process to a desired accuracy or precision. This last point is key in the consideration of LCP. Arguably, the shortest description of the overall LCP execution process is associated with its articulation of SBOs whether they be broad outcomes or more granular objectives. At a higher level of precision, we can specify the key performance indicators (KPIs) and even the most refined description of scope composed of the smallest set of elements essential for SBO achievement. This would correspond to the minimum set of needs that the project must address. The subsequent addition of wants adds no more precision but rather acts to increase the description length.
- **Universal Quantum Turing Machine (UQTM):** Similar to classical Kolmogorov complexity, Quantum Kolmogorov complexity relies on a model of computation called the Universal Quantum Turing Machine (UQTM). The UQTM can simulate any quantum algorithm and is capable of encoding and decoding quantum states and processes. Large, complex projects pose significant challenges due to their scale, technical intricacies, and uncertainties. Complexity increases with project size, leading to unforeseen difficulties and changing conditions during execution. Managing LCP effectively requires innovation and adaptability throughout the project lifecycle.

While UQTMs are primarily associated with quantum computational complexity, they can also inform project management strategies. Large complex projects must innovate continuously; focus on uncertainty; embrace innovation; and be agile and adaptable, dynamically, recognizing change is the only constant.

- **Encoding:** The UQTM is used to encode quantum states or processes into classical descriptions. This encoding process should be reversible, meaning that the original quantum state or process can be accurately reconstructed from the classical description. This is an area of particular challenge for LCP where we remain anchored to a classical PM theory that regularly fails us. Quantum Project Management opens this aperture.
- **Complexity Measure:** Quantum Kolmogorov complexity is defined as the length of the shortest classical description that uniquely specifies the quantum state or process, up to a desired precision. It captures the irreducible information content of the quantum state or process.

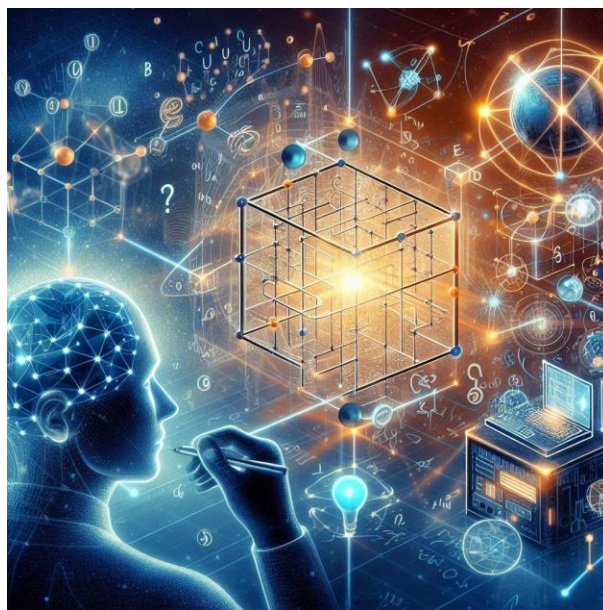
- **Algorithmic Complexity:** Unlike classical Kolmogorov complexity, which relies on specific Turing machines, Quantum Kolmogorov complexity allows for different models of quantum computation, such as quantum circuits, quantum algorithms, or other quantum computational models. Assessing complexity in LCP requires us to consider and use an expanded tool set, especially those tools which recognize the quantum nature of LCP.

Calculating Quantum Kolmogorov complexity involves finding the shortest classical description that accurately represents the quantum state or process. The choice of encoding scheme, precision level, and computational model may affect the calculated complexity. However, the concept remains grounded in the idea of capturing the essential information content of the quantum system or process in a minimal classical description.

Quantum Kolmogorov complexity is a theoretical concept that provides insights into the nature of quantum information and computation, and its practical applications are still an area of active research in quantum information theory and quantum computation.

Quantum Fisher Information

Quantum Fisher information is a key concept in quantum metrology (scientific study of measurement) and quantum estimation theory. It quantifies the sensitivity of a quantum state to small perturbations in a particular parameter that characterizes the state. In LCP we see the consequential impacts of even small perturbations in the broader stakeholder ecosystem.



The Fisher information matrix provides a measure of the amount of information that a quantum state carries about the parameter of interest.

Solving large-scale optimization problems (e.g., logistics, resource allocation, LCP project execution networks) is challenging. Fisher information guides the search for optimal solutions using quantum annealing (optimization process that leverages quantum mechanics to find the global minimum of a given objective function over a set of candidate solutions; helpful in solving the traveling salesman problem; specifically considers the effect of quantum tunneling a phenomena ignored in classical project modeling) or adiabatic quantum computing (bridges classical and quantum worlds, offering an alternative route to solving optimization problems and revealing deep connections to complexity theory). Quantum simulators can also benefit from Fisher information to efficiently simulate complex quantum systems such as what we see in LCP.

A description of Quantum Fisher information and how it is calculated follows:

- **Parameterized Quantum State:** Consider a quantum system described by a parameterized family of density matrices used to represent the parameter of interest that we want to estimate. This parameter could be, for example, the phase of a quantum state or the strength of an interaction.
- **Quantum Measurement:** We perform a measurement on the quantum state to estimate the parameter. The measurement outcomes are associated with probability distributions determined by the quantum state and the parameter.
- **Probability Distribution:** The probability distribution of measurement outcomes depends on the parameter. By performing measurements on identically prepared quantum states, we can gather statistics about the outcomes.
- **Log-Likelihood Function:** The log-likelihood function quantifies how likely the observed measurement outcomes are for different values of the parameter. It is defined as the logarithm of the probability of observing the measurement outcomes given the parameter.
- **Quantum Fisher Information Matrix:** The Quantum Fisher information matrix is defined as the second derivative of the log-likelihood function with respect to the parameters.
- **Quantum Cramér-Rao Bound:** The Quantum Cramér-Rao bound establishes a lower bound on the variance of any unbiased estimator of the parameter. It is inversely proportional to Quantum Fisher information.

In summary, Quantum Fisher information quantifies the amount of information that a quantum state contains about a parameter of interest. It provides a fundamental limit on the precision of parameter estimation achievable with quantum measurements. Calculating the Quantum Fisher information involves analyzing the properties of the quantum state and its sensitivity to variations in the parameters.

Potential applications to assessment of LCP likely exist and are yet to be fully explored.

Conclusion

Quantum Project Management draws analogies from relativistic and quantum theories to describe behaviors in large complex projects by exploring the concepts of scale and complexity. Just as in quantum systems, where complexity arises from the intricate interplay between multiple quantum states and their superposition, entanglement, and interference effects, large complex projects exhibit similar characteristics due to their scale, technical intricacies, uncertainties, and changing conditions during execution.

In the realm of quantum physics, complexity is often described in terms of quantum entanglement and the intricate relationships between quantum particles. Similarly, in large complex projects, complexity arises from the entangled states where the properties of different project components become interdependent, leading to a highly interconnected and nuanced structure.

By drawing parallels between quantum phenomena and the behaviors observed in large complex projects, Quantum Project Management highlights the non-intuitive nature of both systems and the challenges in predicting and controlling their behaviors. This approach allows project managers to consider the unique characteristics of large complex projects, such as the degree of interdependence between project elements, uncertainty, and emergent properties, and adapt management strategies accordingly to enhance innovation, adaptability, and overall project success.

In summary, Quantum Project Management leverages the principles of quantum and relativistic theories to provide a new perspective on managing large complex projects, emphasizing the importance of understanding and addressing the inherent complexities and uncertainties that arise in such endeavors.

Key insights include:

- **Understanding Complexity:** Quantum analogies such as entanglement entropy and quantum circuit complexity offer a new framework for understanding the interconnected nature of project elements and the challenges posed by uncertainties and emergent properties in LCPs.

- **Managing Uncertainty:** Computational complexity measures and quantum complexity classes provide tools for assessing and managing the computational resources and interdependencies within LCPs, enabling project managers to make informed decisions in the face of uncertainty.
- **Enhancing Adaptability:** By leveraging quantum concepts such as Quantum Fisher Information and Quantum Kolmogorov Complexity, project managers can gain insights into the fragility of project plans and the intrinsic complexity of LCPs, leading to more adaptive and resilient project management strategies.
- **Strategic Decision-Making:** Quantum Project Management opens up new avenues for strategic decision-making in LCPs, offering a deeper understanding of the interconnectedness of project components, the nature of complexity classes, and the importance of modularization and precedence minimization.

Overall, this exploration of Quantum Project Management in the context of LCPs highlights the importance of embracing complexity, uncertainty, and interdependencies as inherent aspects of project management. By applying quantum analogies and measurement approaches, project managers can enhance their ability to navigate the complexities of LCPs, drive innovation, and achieve successful project outcomes in an ever-evolving landscape of large complex projects.

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Bob Prieto is Chairman & CEO of Strategic Program Management LLC focused on strengthening engineering and construction organizations and improving capital efficiency in large capital construction programs. Previously Bob was a senior vice president of Fluor focused on the development, delivery and turnaround of large, complex projects worldwide across the firm's business lines, and Chairman of Parsons Brinckerhoff.

Bob's board level experience includes Parsons Brinckerhoff (Chairman); Cardno (ASX listed; Non-executive director); Mott MacDonald (Independent Member of the Shareholders Committee); and Dar al Riyadh Group (current)

Bob consults with owners of large, complex capital asset programs in the development of programmatic delivery strategies encompassing planning, engineering, procurement, construction, financing, and enterprise asset management. He has assisted engineering and construction organizations improve their strategy and execution and has served as an executive coach to a new CEO. He is author of nine books, 950 papers and National Academy of Construction Executive Insights, and an inventor on 4 issued patents.

Bob's industry involvement includes ASCE Industry Leaders Council, National Academy of Construction and Fellow of the Construction Management Association of America (CMAA). He serves on the New York University Abu Dhabi Engineering International Advisory Council and previously served as a trustee of Polytechnic University and the Millennium Challenge Corporation Advisory Board. He was appointed as an honorary global advisor for the PM World Journal and Library.

Bob served until 2006 as one of three U.S. presidential appointees to the Asia Pacific Economic Cooperation (APEC) Business Advisory Council (ABAC). He chaired the World Economic Forum's Engineering & Construction Governors and co-chaired the infrastructure task force in New York after 9/11. He can be contacted at rpstrategic@comcast.net.