Quantum Computing for Construction Robots: Challenges and Opportunities

Ci-Jyun Liang[1], Logan Norton-Lapsley[1], and Zhaofeng Hu[1]

[1]Department of Civil Engineering, Stony Brook University, USA

ci-jyun.liang@stonybrook.edu, logan.norton-lapsley@stonybrook.edu, zhaofeng.hu@stonybrook.edu

Abstract -

Construction robotics play a crucial role in the architecture, engineering, and construction (AEC) industry, but they face significant computational challenges due to dynamic environments, multi-agent coordination, and large-scale combinatorial optimization problems. Quantum computing (QC) offers potential advantages for large-scale search and combinatorial tasks, but its relevance to construction robotics remains unclear. This paper presents a scoping review of QC in robotics. We first collect literature using keyword search from Scopus and Web of Science databases, and then screen through data and include related literature following PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews). We analyze the 96 included studies using bibliometric and thematic analyses to identify research trends and challenges for construction robotics. Results show growing interest in QC robotics since 2020, with dominant applications in path planning, kinematics and control, multi-robot coordination, and decision-making. We identify key barriers to applying QC in construction robotics, including current hardware limitations, simulation-to-real gaps, stringent safety and explainability requirements, and suggest future research directions, including hybrid quantum–classical approaches, QC robotics benchmarks, and explainable QC.

Keywords -

Construction Robotics; Quantum Computing; Scoping Review; Path Planning; Swarm Robotics; Manipulators

1 Introduction

Construction robots have emerged as an important player in the architecture, engineering, and construction (AEC) industry for improving productivity, safety, and quality of the process [1, 2]. Construction robots have been developed for a wide range of tasks, including digital fabrication, on-site assembly, inspection, material handling, and demolition [2]. Recent advances in sensing, reasoning, and control have enabled construction robots to operate in unstructured environments and collaborate with human workers [1]. However, despite notable progress, construction robotics remains constrained by the complexity of construction sites, which are characterized by dynamic changes, diverse materials, limited spaces, and the need for coordination among multiple agents (human workers and robots). Many construction robotics problems, such as task allocation, construction sequencing, motion planning, and multi-robot coordination, show a significant increase in complexity [3]. As the scale and uncertainty of the construction problem increase, classical computational methods often struggle to find solutions within practical time limits, particularly when global optimality or robust and timely decision-making is required. These limitations hinder the scalability, adaptability, and autonomy of construction robotics in real-world deployments [4].

Quantum Computing (QC) has recently raised attention as a potential method for addressing computational intractability that is challenging for classical computing. Unlike classical computing, which processes information using binary states, QC utilizes superposition and entanglement to explore large spaces more efficiently [5, 6, 7]. While QC is still in the early stage and not yet scalable for real-time robot control, emerging QC approaches, such as quantum annealing and hybrid quantum frameworks, offer promising opportunities for civil engineering and robotics applications in, for instance, offline programming, scheduling, and optimization tasks [6, 7]. These capabilities suggest that QC has the potential to advance classical construction robots by addressing their computational limitations through more effective and efficient planning and coordination in complex environments.

Given the developing state of QC and robotics and the limitations of construction robotics, it is necessary to systematically explore existing knowledge, challenges, and research directions in these fields. This paper conducts a scoping review to investigate the current status of QC robotics research and how these may support construction robotics research. The objective of this study is to identify research trends, conceptual themes, and gaps in the QC robotics literature, and to analyze their relevance to construction robotics in order to determine challenges and future research directions for integrating QC into construction robotics. The following three research questions will be addressed in this paper: 1) What are the main research methods, applications, and evaluations in the existing literature on QC and robotics? 2) What are the most common keywords in QC and robotics research? 3) What are the challenges for applying QC in construction robotics?

2 Background

2.1 Quantum Computing

Quantum computing (QC) is a computational paradigm that exploits quantum mechanics phenomena, such as superposition, entanglement, and interference, to perform information processing [8]. Unlike classical binary bits, quantum bits (qubits) can exist in coherent superpositions of basis states, which is described as a state vector in a two-dimensional complex Hilbert space $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$, where α and β are complex numbers that represent probability amplitudes and satisfy $|\alpha|^2 + |\beta|^2 = 1$. Computation proceeds through sequences of quantum gates (unitary operations) acting on single- and multi-qubit states, followed by measurement that probabilistically yields classical outcomes. Entanglement among qubits introduces non-classical correlations that support algorithmic speedups over classical approaches [8].

The potential of QC has been demonstrated through various algorithms. Shor's algorithm provides a polynomial-time solution to integer factorization on fault-tolerant quantum computers [8], while Grover's algorithm provides a quadratic speedup for unstructured search and optimization problems [9]. These algorithms lay the foundation for quantum-inspired robotics algorithms, where search and optimization are pervasive computational bottlenecks [6].

Several physical platforms, including superconducting circuits, topological qubits, trapped ions, neutral atoms, photonic processors, and quantum dots, are being explored to develop scalable quantum computers. Current devices largely operate in the noisy intermediate-scale quantum (NISQ) regime, which motivates hybrid quantum-classical algorithms that combine quantum circuits with classical optimizations [10]. As a result, QC is viewed as a complementary computational resource rather than a replacement for classical computing.

2.2 Quantum Computing in Civil and Construction Engineering

Recent research has begun to explore the potential of quantum computing (QC) and quantum-inspired computing for civil and construction engineering problems that are computationally challenging for classical methods, especially for large-scale optimization and decision-making. Although fault-tolerant quantum computers are not yet available, early studies suggest that hybrid and quantum-inspired approaches can already provide value for some tasks. Ploennigs et al. [11] conducted a multivocal review and showed that most existing applications in civil engineering focus on optimization problems that are reformulated as quadratic unconstrained binary optimization (QUBO) or Ising models. Example applications include structural optimization, structural health monitoring sensor placement, transportation and network analysis, and construction scheduling. The review also suggests that quantum-inspired algorithms implemented on classical hardware are the most practical approach for near-term impact.

In construction perspectives, Zavaleta [12] proposed the integration of QC with robotics and digital twins for real-time structural assessment and seismic optimization. While this paper is largely conceptual, it illustrates how quantum-inspired optimization and simulation could support safety decision-making in construction robotic systems. Chen et al. [5] reviewed QC applications in prefabricated construction supply chains, which shows that production scheduling, inventory management, and transportation routing can be formulated as combinatorial optimization problems amenable to quantum annealing and hybrid quantum-classical algorithms such as the quantum approximate optimization algorithm (QAOA). This study also highlights persistent challenges, including hardware limitations, data integration with existing tools, and the need for construction-specific quantum formulations. In summary, existing review studies focus on QC in civil and construction engineering applications but the review of QC and construction robotics remains unexplored.

3 Methodology

We conduct a scoping review to explore existing research on quantum computing (QC) and robotics and analyze research trends and gaps in construction robotics applications. The scoping review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR) framework to ensure transparency and reproducibility. We first collect the relevant literature from the major databases Scopus and Web of Science (WoS) as they are most commonly used in engineering review research [1, 2, 5]. The search string used in Scopus and WoS is `(TITLE-ABS-KEY("quantum computing") AND TITLE-ABS-KEY(robot*))`. The search results are limited to journal articles, conference papers, book chapters, and English-language publications. The data was collected on 10/29/2025 and uploaded to Covidence (a systematic review tool) for further screening and review. The initial search result contains 699 articles (407 from Scopus and 783 from WoS, of which 491 are duplicates).

Figure 1 illustrates the scoping review process and results. First, all initial search articles were screened through the abstract and only relevant ones were passed to the full-text review (n=118). Most irrelevant articles focus on QC and robotics themselves, not on their combination. We also removed the review paper since we only focus on technical papers. Second, all relevant articles were reviewed in full text and determined to be truly relevant. Twenty-two articles are excluded due to not QC-related (n=6), not robot-related (n=9), review paper (n=1), low quality (n=4), or full-text unavailable (n=2). Finally, the scoping review process resulted in 96 articles. Bibliometric and thematic analyses are performed on the included studies to identify keyword co-occurrence, robot topics, QC methods, and experimental results.

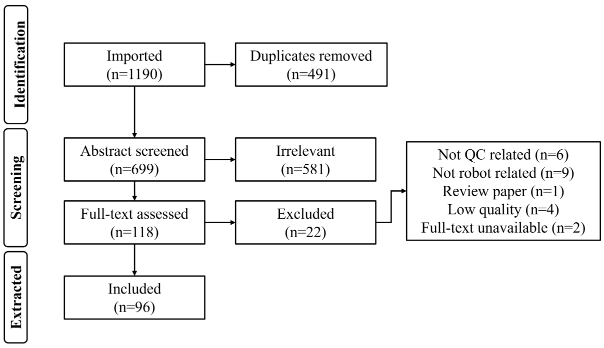

Figure 1. Scoping review process and results

4 Bibliometric Analysis

To answer the second research question, we conduct a bibliometric analysis to find the research trends among the included studies. First, we examine the number of publications by year, as shown in Figure 2. In the early stage (2006-2014), QC robotics publications were low and infrequent. In the intermediate stage (2015-2019), the yearly publication increased gradually as the QC methods were consolidating. In the recent stage (2020-2025), the number of publications began to scale, with a sharp surge in 2024-2025. This indicates a strong interest in the QC robotics field. This trend aligns with technological and external factors of QC development, such as the maturation of NISQ-era quantum hardware and growing public and private sectors investment. Although the highest number is 18 articles, it is still a significant increase from the early stage, when there were 1-3 articles per year. Overall, the result indicates a transition from exploratory work to a more mature and application-rich phase.

Second, we conduct the keyword co-occurrence analysis. Figure 3 shows the keyword co-occurrence map. As expected, the keyword "quantum computing" is the most common in the included studies and has the strongest connection to other keywords. There are four clusters centered around "quantum computing." The first cluster is "quantum computing and robots" (blue and cyan), which contains quantum computing, robots, quantum annealing, reinforcement learning, and quantum mechanics.

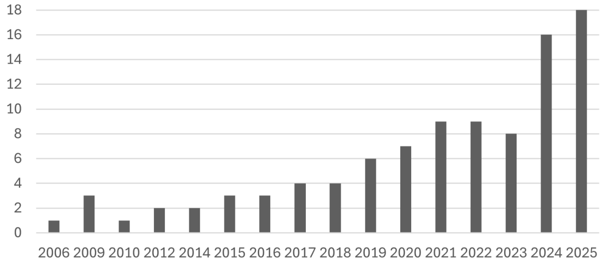

Figure 2. Number of publications by year

The second cluster is "path planning and optimization" (red), which contains path planning, optimization, mobile robots, inverse kinematics, and particle swarm optimization. The third cluster is "swarm robotics" (yellow and purple), which contains swarm robotics, convergence, task allocation, robot sensing systems, and collision avoidance. The fourth cluster is "quantum algorithms" (green), which contains quantum algorithms, machine learning, computational modeling, and artificial intelligence. The cluster results indicate that the most common QC robotics research areas are planning and optimization, as well as the application of existing QC algorithms to various types of robotics. Table 1 lists the top ten occurring keywords and the number of occurrences. These keywords align with the dominant keywords in each cluster. "Quantum computing," "Path planning," "Robots," and "Optimization" are the top four keywords and have over ten occurrences. This indicates that most of the QC robotics research focuses on expediting path planning and optimization problems where computational capacity is often constrained. Another finding in the keywords is that the robots are divided into more specific types of robots (e.g., mobile robots, swarm robots, and robot sensing systems), which are usually associated with path planning and optimization research.

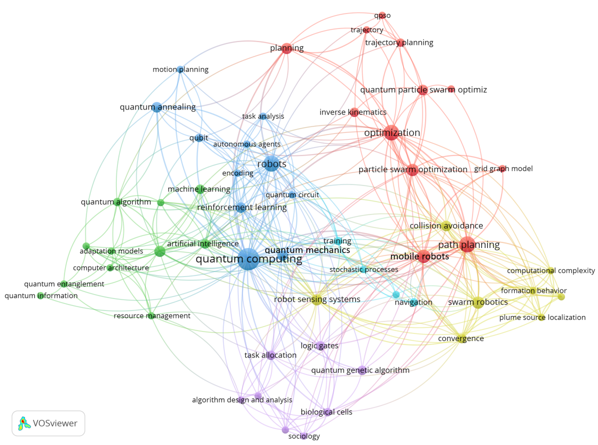

Figure 3. Keyword co-occurance analysis

Table 1. Top ten occurring keywords

Keyword	Occurrences
Quantum computing	33
Path planning	15
Robots	14
Optimization	13
Mobile robots	9
Particle swarm optimization	7
Swarm robotics	7
Computational modeling	6
Robot sensing systems	6
Planning	6

5 Thematic Analysis

Based on the bibliometric analysis and full-text review, we categorize the included research into four themes: 1) Path Planning and Navigation, 2) Kinematics, Trajectory Optimization, and Control, 3) Multi-Robot Coordination, Swarms, and Task Allocation, and 4) Algorithms and Decision-Making. These themes capture how QC translates into computational benefits for robotics. The thematic analysis also answers the first research question.

5.1 Theme 1: Path Planning and Navigation

A major portion of the studies in this theme focuses on accelerating or improving global and local navigation for autonomous robots using quantum and quantum-inspired algorithms. For example, quantum-behaved particle swarm optimization (QPSO), quantum genetic algorithm (QGA), and quantum-enhanced search (Grover, amplitude amplification) can identify shorter robot paths, faster convergence, smoother trajectories, and better obstacle avoidance than classical baselines. This research theme typically solves single mobile robot path planning questions. Representative work includes QPSO-based planner [13], Grover's search [14], QGA-based optimization [15], quantum RRT [16], quantum-enhanced reinforcement learning [17], and quantum annealing for trajectory optimization [18]. Several studies demonstrated real-time feasibility in partially known or dynamically changing maps [13], or incorporated perception-driving planning for localization [15]. These methods are especially relevant for construction robots navigating cluttered, unstructured, and reconfigurable environments. For construction robotics, these planning methods are suitable for navigating cluttered, dynamically changing sites, where narrow pathways, temporary obstacles, and safety zones block planned paths. Their ability to perform global or near-global optimization is valuable for offline planning and rapid replanning in large-scale construction environments.

5.2 Theme 2: Kinematics, Trajectory Optimization, and Control

The second theme includes quantum and quantum-inspired approaches for inverse kinematics (IK), forward kinematics (FK), trajectory generation, calibration, and closed-loop control. Robot manipulators are the primary type of robot in this research theme. Studies show that QPSO, QGA, and quantum-activated neural networks outperform the classical optimization algorithms in IK/FK accuracy, convergence speed, and robustness [19, 20]. Trajectory optimization applies QGA and QPSO for smooth and collision-free arm motion and demonstrates reductions in tracking error, energy consumption, and mobile manipulators base disturbance [21]. Quantum-enhanced control systems, such as QFI-based, QSAC reinforcement learning-based, and quantum-PID controllers, highlight the robustness to disturbances, actuator faults, and model uncertainty [22]. These results imply the potential for construction manipulators, which often operate in tight and constrained spaces, requiring precise IK and controller under redundancy, singularity risk, and dynamic loads. These approaches are well-suited for construction manipulators operating in constrained workspaces, such as robot assembly tasks under load variation and collision constraints. Quantum-inspired trajectory optimization can support precise, smooth, and energy-aware motions when classical solvers struggle with kinematic constraints.

5.3 Theme 3: Multi-Robot Coordination, Swarms, and Task Allocation

The third theme focuses on collective robotics, where multiple agents coordinate tasks, share constraints, or operate as swarms. Quantum computing methods are advantageous due to their ability to explore combinatorial solution spaces more efficiently and support multi-agent policies. For multi-robot task allocation and coalition formation, quantum-evolutionary and quantum-multi-objective formulations produce faster, more diverse, and optimal allocations than classical methods [23, 24]. In swarm robotics, quantum-behaved cooperative navigation and distribution methods, entanglement-inspired methods, and hybrid RL methods improve coverage, convergence speed, and robustness in constrained and partially observed environments [25, 26]. Multi-robot scheduling and allocation using quantum annealing also demonstrate the applicability for industrial workflows [27]. Their scalability is important for large-scale construction operations involving fleets of autonomous mobile robots, aerial robots, and multi-arm cooperative systems. In large-scale construction settings, quantum-based and quantum-inspired methods have potential for managing fleets of heterogeneous robots performing interdependent tasks in shared spatial, temporal, and resource constraints.

5.4 Theme 4: Algorithm and Decision-Making

The final theme consists of quantum-enhanced reinforcement learning algorithms and decision-making architectures that do not address robot navigation or control. These studies explore how QC enables rapid learning, policy representations, multimodal reasoning, and reduced model size. Quantum reinforcement learning methods demonstrate improvements in sample efficiency, convergence speed, and generalization [28]. Decision-making frameworks based on quantum logic or Grover's algorithm highlight how quantum principles can encode uncertainty and probabilistic behavior more naturally than classical models [29]. Several studies extend to creative trajectory generation and agricultural and industrial robots [30, 31], which further illustrate how domain-specific QC can support complex reasoning and decision-making beyond motion planning. For construction, these methods provide abilities for adaptive tasks sequencing, risk-aware action selection, and resource-limited robots, which are essential for human-robot collaboration on dynamic and hazardous construction sites.

5.5 Experiments and Evaluations Methods

To answer the first research question, we compare the included literature based on the experiments and evaluation methods used. Although the research focuses are diverse, several consistent patterns emerge across simulation environments, physical hardware tests, quantum hardware use, and benchmarking metrics. Most included studies validate their proposed quantum or quantum-inspired algorithms in simulation, reflecting the early maturity of quantum technologies. Path planning and navigation studies use 2D or 3D grid-based environments, structured lattice worlds, or dynamic map simulations to evaluate path optimality, collision avoidance, and convergence speed [14, 16, 17, 18]. Manipulator-focused studies rely on physics-based robotics simulators to test IK accuracy, trajectory smoothness, and control robustness [19, 22]. Swarm robotics and collective decision-making algorithms often combine robotics simulators such as Webots with quantum circuit simulators such as IBM Qiskit to evaluate performance [25, 28].

Some studies conducted physical robot experiments, providing evidence of real-world feasibility. Examples include comparing different algorithms for solving IK on a real robot manipulator [20] or evaluating a real escort robot prototype in different scenarios [32]. These experiments confirm that quantum-inspired optimization can yield measurable improvements in accuracy, robustness, and stability on actual robot systems at a limited scale. On the other hand, several studies evaluate algorithms on real quantum hardware such as D-Wave annealers and IBM quantum processors [25, 27]. These results highlight the feasibility of quantum hardware but also its current limitations, such as limited qubit count, noise, and embedding overhead, which restrict problem sizes to small scales.

In terms of evaluation metrics, path planning studies measure path length, smoothness, collision-free success rate, and computation time [15, 16, 18]. Manipulation and control studies assess position and orientation error, tracking error, and disturbance rejection capability [19, 20, 21, 22]. Multi-robot coordination studies compare allocation quality, solution diversity, coverage efficiency, and energy consumption [23, 25]. Decision-making and RL studies evaluate sample efficiency, accumulated rewards, learning speed, and decision accuracy [26, 28].

For most of the experiment results, quantum-inspired methods (e.g., QPSO, QGA, hybrid quantum) outperform classical baselines such as GA, PSO, artificial bee colony (ABC), simulated annealing, and deep RL methods. Quantum hardware-based approaches show conceptual promise but have yet to exceed classical methods except on certain small-scale instances. Overall, the evaluation of the included studies reveals that quantum-inspired algorithms are mature and practical for deployment, while quantum-native hardware solutions remain exploratory.

6 Challenges of QC in Construction Robots

Based on the thematic analysis, we identify four challenges that limit the deployment of QC for construction robotics. This also answers the third research question.

6.1 QC Hardware Limitation

Previous studies on real QC hardware confirm that current QC hardware can solve only small to modest problem instances, with solution quality and success rate deteriorating as problem size increases. Quadratic Unconstrained Binary Optimization (QUBO) and Ising models for routing, scheduling, and motion planning on D-Wave 2000Q demonstrate feasibility but expose minor embedding overhead, chain breaks, and decreasing success rate as the number of variables and coupling constraints increases [27, 33]. Circuit-based robotics (e.g., Grover's algorithm) shows concept validity on IBM superconducting devices, but qubit counts, noise, and circuit depth limits constrain path complexity and state encodings [25]. In benchmarking, classical simulated annealing and heuristics often outperform quantum annealing on larger or denser instances [33]. For construction robotics, the site scale is extremely large. For example, mobile robots path planning for multi-level and large sites with dynamically changing environments and multi-agent task sequencing with resource conflicts will require thousands of variables and hundreds of constraints per shift. The current NISQ devices cannot natively embed these instances without heavy decomposition.

6.2 Sim-to-Real Gap and Physical Validation

Most studies are validated in simulation, grid worlds, or MATLAB physics, with limited noise, simplified dynamics, and static or scripted obstacles. Only a few studies report real robot validations but setups are controlled and small-scale. Construction sites introduce dust, occlusions, glare, vibration, uneven terrain, obstacles, and human movement that are difficult for simulators to reflect. Sensors also have noise that cannot perfectly capture the real-world conditions. Algorithms that performed well in simulations may underperform or fail under sensor dropouts. This is also a well-known challenge called the simulation-to-real-world (sim-to-real) gap, especially in construction robotics [1].

6.3 Perception and Planning Integration

A few studies connect perception to planning, e.g., 3D LiDAR SLAM and QGA planning or Grover localization, but end-to-end processes that feed semantic maps, progress states, and uncertainty into QC solvers are rare. Swarm robotics and path planning studies usually assume fully known maps. Construction-related constraints (e.g., temporary structure and hazard zone) and as-built changes are not modeled. Practical construction robotics depend on turning reality capture (point clouds, SLAM, progress scans) and BIM information into QC constraint sets, such as temporary obstructed zones, crane swing zones, or worker zones. Without this information, QC could optimize for out-of-date or incomplete worlds, which would cause safety issues.

6.4 Safety and Explainability

Quantum-fuzzy inference, quantum genetic tuning, and quantum analytical redundancy deliver strong simulated robustness, such as improved stability and disturbance rejection for mobile robots. However, traceability of decisions, interpretable policies, and safety information are not specified. Robots work alongside workers and heavy equipment require explainable behavior, safety constraints, and transparency [2]. Opaque QC optimizers are difficult to explain and deploy near humans.

7 Future Research Directions

Based on the thematic analysis and challenges associated with construction robotics, we suggest several future research directions. First, hybrid QC approaches for construction robotics that combine the advantages of both QC and classical computing methods. Future systems should use classical heuristics and graph decomposition to generate structured candidate sets and then apply QC methods, such as quantum annealing, to high-leverage subproblems. This hybrid approach, which has been developed in hybrid QUBO path planning [18], can provide promising results before fault-tolerant quantum hardware is available, while avoiding the embedding constraints and latency issues in the current annealing and circuit experiments [33]. Future studies should formalize anytime guarantees and performance bounds for these pipelines and design quantum-ready abstractions that embed efficiently on current hardware.

The second research direction is to create construction-specific QC robotics benchmarks that provide more characteristics of construction sites than simulating grid worlds. Most existing QC robotics evaluations use grid maps or noise-free simulations; only a few studies reflect the roughness of construction sites. Future research should create open benchmarks that combine 3D SLAM maps with BIM or Digital Twin, include dynamic obstacles and time-windowed constraints (e.g., crane swing zones), and provide construction manipulation scenarios. The existing evaluation metrics would enable comparisons among quantum, quantum-inspired, and classical baselines. In addition, integrating QC with BIM or digital twins is necessary to support real-time decision-making using real construction site information.

Third, QC for construction robotics needs to provide safe, explainable, and transparent information for human-robot collaboration. Quantum-fuzzy inference, quantum genetic tuning, and quantum analytical redundancy show promising robustness and fault detection, but they must be integrated with safety constraints (e.g., control barrier functions), traceable decision logs, and human-in-the-loop processes. Future work should investigate methods that summarize quantum controller behavior into human-readable and interpretable rationales, which enable trustworthy deployment near construction workers and heavy equipment.

Finally, economic feasibility and adoption pathways must be considered in future work. Given the high cost of quantum hardware, near-term construction applications are most likely to rely on cloud-based quantum services, quantum simulators, or quantum-inspired algorithms running on classical hardware. The strongest return-on-investment potential lies in offline and supervisory-level applications where modest improvements in solution quality can yield significant productivity and safety benefits. Future studies should assess deployment cost, integration effort, and workforce training requirements.

8 Conclusions

This paper presents a scoping review of 96 studies on quantum computing (QC) in robotics to assess its relevance for construction robotics. The results show rapid growth since 2020, with dominant applications in path planning, kinematics and control, multi-robot coordination and swarm robotics, and algorithm and decision-making. Existing QC robotics studies often use quantum-inspired or hybrid approaches. However, deploying QC for construction robots remains constrained by hardware limitations, limited real-world validation, weak integration of perception and planning, and safety and explainability requirements. The practical impact on the construction field is still limited. Future work should prioritize hybrid quantum–classical pipelines, construction-specific benchmarks, and safety-aware, interpretable decision support.

References

[1] Ci-Jyun Liang, Xi Wang, Vineet R Kamat, and Carol C Menassa. Human–robot collaboration in construction: Classification and research trends. *Journal of Construction Engineering and Management*, 147(10):03121006, 2021. doi:10.1061/(ASCE)CO.1943-7862.0002154.

[2] Ci-Jyun Liang, Thai-Hoa Le, Youngjib Ham, Bharadwaj RK Mantha, Marvin H Cheng, and Jacob J Lin. Ethics of artificial intelligence and robotics in the architecture, engineering, and construction industry. *Automation in Construction*, 162:105369, 2024. doi:10.1016/j.autcon.2024.105369.

[3] Zhaofeng Hu and Ci-Jyun Liang. LLM-PCPP: A novel robot prioritized coverage path planning approach for complex environments. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*, volume 42, pages 250–257. IAARC, 2025. doi:10.22260/ISARC2025/0034.

[4] Stefana Parascho. Construction robotics: From automation to collaboration. *Annual Review of Control, Robotics, and Autonomous Systems*, 6(1):183–204, 2023. doi:10.1146/annurev-control-080122-090049.

[5] Zhen-Song Chen, Yue Tan, Zheng Ma, Zhengze Zhu, and Miros law J Skibniewski. Unlocking the potential of quantum computing in prefabricated construction supply chains: Current trends, challenges, and future directions. *Information Fusion*, page 103043, 2025. doi:10.1016/j.inffus.2025.103043.

[6] Fei Yan, Abdullah M Iliyasu, Nianqiao Li, Ahmed S Salama, and Kaoru Hirota. Quantum robotics: a review of emerging trends. *Quantum Machine Intelligence*, 6(2):86, 2024. doi:10.1007/s42484-024-00225-5.

[7] Joern Ploennigs, Kay Smarsly, Markus Berger, Kosmas Dragos, and Martin Kliesch. Quantum and quantum-inspired computing in civil engineering. *Advanced Engineering Informatics*, 69:103960, 2026. doi:10.1016/j.aei.2025.103960.

[8] Michael A. Nielsen and Isaac L. Chuang. *Quantum Computation and Quantum Information: 10th Anniversary Edition*. Cambridge University Press, 2010.

[9] Lov K. Grover. A fast quantum mechanical algorithm for database search. In *Proceedings of the Twenty-Eighth Annual ACM Symposium on Theory of Computing*, page 212–219. ACM, 1996. doi:10.1145/237814.237866.

[10] John Preskill. Quantum computing in the NISQ era and beyond. *Quantum*, 2:79, 2018. doi:10.22331/q-2018-08-06-79.

[11] Joern Ploennigs, Kay Smarsly, Markus Berger, Kosmas Dragos, and Martin Kliesch. Quantum and quantum-inspired computing in civil engineering. *Advanced Engineering Informatics*, 69:103960, 2026. doi:https://doi.org/10.1016/j.aei.2025.103960.

[12] Jorge Pablo Aguilar Zavaleta. Building construction using robots performing structural calculations in real time with quantum computers for seismic optimization. *Journal of Scientific Engineering Advances*, 2025. doi:10.63721/25JSEA0102.

[13] Zheng Zeng, Karl Sammut, Andrew Lammas, Fangpo He, and Youhong Tang. Efficient Path Re-planning for AUVs Operating in Spatiotemporal Currents. *Journal of Intelligent & Robotic Systems*, 79 (1):135–153, July 2015. doi:10.1007/s10846-014-0104-z.

[14] Unai Antero, Basilio Sierra, Jon Oñativia, Alejandra Ruiz, and Eneko Osaba. Robot localization aided by quantum algorithms. *Robotics and Autonomous Systems*, 192:105026, October 2025. doi:10.1016/j.robot.2025.105026.

[15] Shih-An Li, Yun-Chien Chen, Bo-Xian Wu, and Hsuan-Ming Feng. 3D lidar SLAM-based systems in object detection and navigation applications. *Journal of the Chinese Institute of Engineers*, 46(8):912–925, November 2023. doi:10.1080/02533839.2023.2261983.

[16] Paul Lathrop, Beth Boardman, and Sonia Martínez. Quantum Search Approaches to Sampling-Based Motion Planning. *IEEE Access*, 11:89506–89519, 2023. doi:10.1109/ACCESS.2023.3307316.

[17] Hans Hohenfeld, Dirk Heimann, Felix Wiebe, and Frank Kirchner. Quantum Deep Reinforcement Learning for Robot Navigation Tasks. *IEEE Access*, 12:87217–87236, 2024. doi:10.1109/ACCESS.2024.3417808.

[18] Scott Howard James and Robert Nicholas Raheb. Path Planning for Critical ATM/UTM Areas. In *2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC)*, pages 1–6, September 2019. doi:10.1109/DASC43569.2019.9081662.

[19] Serkan Dereli and Raşit Köker. A meta-heuristic proposal for inverse kinematics solution of 7-DOF serial robotic manipulator: quantum behaved particle swarm algorithm. *Artificial Intelligence Review*, 53 (2):949–964, February 2020. doi:10.1007/s10462-019-09683-x.

[20] Mustafa Ayyıldız and Kerim Çetinkaya. Comparison of four different heuristic optimization algorithms for the inverse kinematics solution of a real 4-DOF serial robot manipulator. *Neural Computing and Applications*, 27(4):825–836, May 2016. doi:10.1007/s00521-015-1898-8.

[21] Jianxia Zhang, Fuchao Yang, Guanghua Nie, and Jianxin Zhang. Optimal Trajectory Planning for Minimizing Base Disturbance of a Redundant Space Robot with IQPSO. *Journal of Electrical and Computer Engineering*, 2022(1):3398810, 2022. doi:10.1155/2022/3398810.

[22] M. S. Katulin and S. V. Ulyanov. Simulator of a robust intelligent robotic manipulator control system: The application of knowledge base optimizer on quantum computing—QCOptKB. *Physics of Particles and Nuclei*, 55(3):541–544, 2024. doi:10.1134/S106377962403047X.

[23] Farouq Zitouni, Ramdane Maamri, and Saad Harous. FA–QABC–MRTA: A solution for solving the multi-robot task allocation problem. *Intelligent Service Robotics*, 12(4):407–418, 2019. doi:10.1007/s11370-019-00291-w.

[24] Zhiyong Li, Bo Xu, Lei Yang, Jun Chen, and Kenli Li. Quantum evolutionary algorithm for multi-robot coalition formation. In *Proceedings of the First ACM/SIGEVO Summit on Genetic and Evolutionary Computation*, page 295–302, New York, NY, USA, 2009. Association for Computing Machinery. doi:10.1145/1543834.1543874.

[25] Maria Mannone, Valeria Seidita, and Antonio Chella. Modeling and designing a robotic swarm: A quantum computing approach. *Swarm and Evolutionary Computation*, 79:101297, 2023. doi:10.1016/j.swevo.2023.101297.

[26] Won Joon Yun, Jae Pyoung Kim, Soyi Jung, Jae-Hyun Kim, and Joongheon Kim. Quantum multiagent actor–critic neural networks for internet-connected multirobot coordination in smart factory management. *IEEE Internet of Things Journal*, 10(11):9942–9952, 2023. doi:10.1109/JIOT.2023.3234911.

[27] Moritz Willmann, Marcel Albus, Jan Schnabel, and Marco Roth. Application of quantum annealing for scalable robotic assembly line optimization: a case study. *Procedia CIRP*, 134:25–30, 2025. ISSN 2212-8271. doi:10.1016/j.procir.2025.01.099.

[28] Ahmad Alomari and Sathish A. P. Kumar. ReLAQA: Reinforcement learning-based autonomous quantum agent for quantum applications. *IEEE Transactions on Artificial Intelligence*, 6(3):549–558, 2025. doi:10.1109/TAI.2024.3437335.

[29] Daoyi Dong, Chunlin Chen, Chenbin Zhang, and Zonghai Chen. Quantum robot: structure, algorithms and applications. *Robotica*, 24(4):513–521, 2006. doi:10.1017/S0263574705002596.

[30] Peng Mei, GangYi Ding, QianKun Jin, FuQuan Zhang, and YangFan Jiao. Quantum-based creative generation method for a dancing robot. *Frontiers in Neurorobotics*, 14, 2020. doi:10.3389/fnbot.2020.559366.

[31] Prashant Khobragade, Praveen Kumar Dhankar, Abhijit Titarmare, Mrunali Dhone, Shruti Thakur, and Pranay Saraf. Quantum-enhanced ai robotics for sustainable agriculture: Pioneering autonomous systems in precision farming. In *2024 International Conference on Artificial Intelligence and Quantum Computation-Based Sensor Application (ICAIQSA)*, pages 1–7, 2024. doi:10.1109/ICAIQSA64000.2024.10882412.

[32] Ming-hai Jiao, He-xiang Wei, Bo-wen Zhang, Jia-qi Jin, Zhen-qiang Jia, and Jun-lang Yan. Path planning of escort robot based on improved quantum particle swarm optimization. In *2019 Chinese Control And Decision Conference (CCDC)*, pages 3730–3735, 2019. doi:10.1109/CCDC.2019.8833185.

[33] Jernej Rudi Finžgar, Philipp Ross, Leonhard Hölscher, Johannes Klepsch, and Andre Luckow. QUARK: A Framework for Quantum Computing Application Benchmarking. In *2022 IEEE International Conference on Quantum Computing and Engineering (QCE)*, pages 226–237, September 2022. doi:10.1109/QCE53715.2022.00042.