OPEN ACCESS
Journal of Tecnologia Quantica
Vol. 3 No. 1. February 2026, pp. 1-12 DOI. 10.70177/quantica.v2i4.2793
Research Article

Topological Quantum Computation Using Majorana Fermions in Nanowire Networks: A Theoretical Feasibility Study

Loso Judijanto[1], Khalil Zaman[2], Zara Ali[3]
[1] IPOSS Jakarta, Indonesia
[2] Mazar University, Afghanistan
[3] Khost University, Afghanistan

Corresponding Author:

Loso Judijanto,
IPOSS Jakarta, Indonesia
IPOSS Jakarta, lantai 16 Gedung SAhid Sudirman Center, JL. Jenderal Sudirman 86, Jakarta 10220
Email: losojudijantobumn@gmail.com

Article Info

Received: July 9, 2025
Revised: Aug 10, 2025
Accepted: Sep 8, 2025
Online Version: Feb 2, 2026

Abstract

Topological quantum computation offers a promising pathway toward fault-tolerant quantum information processing, with Majorana fermions emerging as key quasiparticles capable of encoding quantum states protected from local decoherence. Nanowire networks engineered to host Majorana zero modes have been widely proposed, yet their practical feasibility requires rigorous theoretical assessment under realistic physical constraints. This study aims to evaluate the theoretical viability of implementing topological quantum computation using Majorana fermions in semiconductor–superconductor nanowire networks. A modeling framework incorporating Bogoliubov–de Gennes equations, topological phase diagrams, non-Abelian braiding protocols, and disorder-induced perturbations is employed to assess stability and control requirements. Simulations investigate parameter regimes involving magnetic field strength, spin–orbit coupling, proximity-induced superconductivity, and wire-junction geometries. The results show that stable Majorana modes can be achieved within narrow but experimentally accessible parameter windows, and that non-Abelian braiding operations remain topologically robust against moderate disorder and quasiparticle poisoning. The study concludes that while significant engineering challenges persist—particularly regarding temperature constraints, material uniformity, and junction coherence Majorana-based topological quantum computation remains theoretically feasible with current technological progress.

Keywords: Majorana Fermions, Nanowire Networks, Non-Abelian Braiding

Journal Homepage	https://research.adra.ac.id/index.php/quantica
How to cite:	Judijanto, L., Zaman, K & Ali, A. (2026). Topological Quantum Computation Using Majorana Fermions in Nanowire Networks: A Theoretical Feasibility Study. *Journal of Tecnologia Quantica, 3*(1), 1–12. https://doi.org/10.70177/quantica.v2i4.2793
Published by:	Yayasan Adra Karima Hubbi

INTRODUCTION

Topological quantum computation has emerged as one of the most promising frameworks for achieving fault-tolerant quantum information processing, primarily because topological states are inherently protected from many forms of environmental decoherence. Quantum systems encoded in topological degrees of freedom offer stability under local perturbations, making them attractive candidates for building scalable quantum computers. Majorana fermions, particularly Majorana zero modes, have gained significant attention as quasiparticles capable of supporting such topologically protected states in engineered condensed-matter systems (Duan et al., 2020; Hwang et al., 2022).

Semiconductor superconductor nanowire platforms have been identified as experimentally accessible environments for generating Majorana zero modes through the interplay of spin orbit coupling, Zeeman splitting, and superconducting proximity effects. Experimental advances over the last decade have demonstrated signatures consistent with Majorana physics, including zero-bias conductance peaks and observations of topological phase transitions. These developments have motivated a growing interest in evaluating whether such nanowire networks can host and manipulate Majorana states reliably enough for computational applications.

The rapid progression of quantum device engineering has intensified the need for theoretical assessments that systematically examine the viability of using Majorana fermions for quantum computation. A clear understanding of the parameter regimes, stability properties, and control requirements is essential for transitioning from proof-of-concept demonstrations toward functional topological qubits. This study responds to the increasing demand for rigorous feasibility analyses that bridge the gap between theoretical predictions and realistic nanowire-based architectures (Herbrych et al., 2021; Komijani, 2020).

The central problem addressed in this research concerns the unresolved question of whether Majorana zero modes in nanowire networks can reliably support the requirements of topological quantum computation under realistic physical conditions. Theoretical models predict topological protection, yet empirical constraints such as disorder, quasiparticle poisoning, and finite temperature effects threaten the stability of Majorana states. The mismatch between idealized theoretical expectations and experimentally observed challenges necessitates a more comprehensive evaluation (Herbrych et al., 2021; H. Wang & Principi, 2021).

A key issue lies in determining whether non-Abelian braiding operations, which form the computational backbone of Majorana-based qubits, remain robust when exposed to noise, fabrication imperfections, and material inhomogeneities. Nanowire junctions must support precise control of Majorana mode positions, yet practical implementations may suffer from reduced coherence, incomplete topological gaps, or perturbations that disrupt braiding fidelity. The feasibility of achieving reliable topological gate operations remains a critical open question.

The research problem thus centers on assessing the theoretical consistency between proposed Majorana-based computation schemes and the actual constraints imposed by realistic nanowire networks. A feasibility study must examine parameter spaces, topological phase diagrams, and sensitivity to disorder to determine whether the envisioned computational framework is stable enough for practical use. Such analysis is essential for clarifying the current limitations and guiding future experimental designs (R.-B. Wang et al., 2020; Zhu et al., 2021).

This study aims to provide a systematic theoretical evaluation of the feasibility of implementing topological quantum computation using Majorana fermions in semiconductor–superconductor nanowire networks. The objective is to examine the stability of Majorana zero modes and their suitability for supporting non-Abelian braiding operations across experimentally relevant parameter regimes. The research seeks to quantify the extent to which realistic constraints affect computational viability.

The study intends to model nanowire networks using Bogoliubov–de Gennes formalism to map topological phase boundaries, evaluate Majorana localization, and simulate braiding dynamics. By examining how Majorana wavefunctions respond to variations in magnetic fields, spin–orbit coupling strengths, chemical potentials, and disorder distributions, the research aims to identify conditions where topological protection is maximized. The simulations provide insights into performance thresholds for stable qubit encoding.

The overarching goal of the research is to determine whether current or near-future nanowire technologies can support the theoretical requirements of topological quantum computation. Establishing feasibility, limitations, and necessary conditions will contribute to the broader effort of transitioning Majorana-based quantum computation from theoretical promise to practical realization. The conclusions of this study are expected to inform both theoretical development and experimental strategies (Kong et al., 2021; Liu et al., 2021).

Existing literature includes extensive theoretical work predicting the emergence of topological superconducting phases and Majorana zero modes in nanowire systems. However, the majority of these studies rely on idealized assumptions such as perfect material uniformity, negligible disorder, and infinitely sharp topological gaps. These conditions often diverge from realistic experimental environments, leaving uncertainty about whether the predicted phenomena remain robust under practical constraints.

Empirical studies reporting Majorana-like signatures frequently lack conclusive evidence that the observed features correspond to true topological zero modes rather than trivial bound states. The ambiguity surrounding experimental interpretation highlights a significant gap in the literature: the absence of systematic frameworks that evaluate computational feasibility rather than mere Majorana detection. Existing works seldom address braiding stability, coherence times, or error susceptibility in detail (Ezawa, 2020; Zhang et al., 2019).

A further gap arises from the limited exploration of nanowire network geometries and junction configurations. Much of the literature focuses on single or dual-wire systems, while computational architectures require multi-wire networks capable of supporting scalable braiding operations. The lack of comprehensive theoretical analyses addressing these geometries restricts understanding of their suitability for quantum computation. This study is positioned to bridge these gaps through a structured feasibility evaluation.

This study introduces a novel theoretical framework that unifies topological phase analysis, disorder sensitivity evaluation, and braiding stability simulations within a single feasibility model. The integration of these components provides a more holistic evaluation than previous works that treat them in isolation. This approach enables a deeper understanding of how key physical parameters interact to influence computational reliability (Y.-P. He et al., 2020; Toikka, 2019).

The research is justified by the urgent need to assess whether Majorana-based topological computation can move beyond conceptual proposals toward experimental and technological viability. Topological quantum computation has long been heralded as a paradigm capable of achieving intrinsic error resilience, yet its practical realization remains uncertain. A rigorous feasibility study provides essential clarity for both theorists and experimentalists navigating the development of topological qubits.

The novelty also lies in addressing experimentally relevant constraints such as quasiparticle poisoning, finite-temperature effects, and material disorder—factors often acknowledged but rarely incorporated into detailed computational models. By grounding the analysis in realistic conditions, this study contributes a meaningful step toward understanding the true potential and limitations of Majorana-based quantum computation. The justification stems from the need to align theoretical expectations with the realities of device physics (Génetay Johansen & Simula, 2022; Groenendijk et al., 2019).

RESEARCH METHOD

This study employs a theoretical–computational research design aimed at evaluating the feasibility of implementing topological quantum computation using Majorana fermions in semiconductor–superconductor nanowire networks. The design integrates analytical modeling of topological superconducting phases with numerical simulations of Majorana localization, braiding dynamics, and disorder effects. The approach prioritizes physical realism by incorporating experimentally relevant parameters such as magnetic field strengths, spin–orbit coupling magnitudes, superconducting gaps, and temperature-dependent coherence limits. The design is structured to capture the interplay between material properties and topological protection mechanisms (Mohapatra et al., 2022; Sturges et al., 2021).

The population of interest consists of nanowire systems capable of supporting Majorana zero modes, specifically hybrid semiconductor–superconductor structures such as InSb or InAs nanowires proximitized by s-wave superconductors. The study samples three representative nanowire configurations: single-wire chains, T-junction networks, and multi-wire braiding loops. These configurations are selected to reflect the spectrum of architectures proposed for Majorana-based topological qubits. The sampling strategy ensures coverage of both minimal systems suitable for Majorana detection and extended networks required for braiding operations.

The instruments used in this research include the Bogoliubov–de Gennes (BdG) formalism for modeling superconducting quasiparticle states, numerical solvers for computing energy spectra and wavefunction localization, and topological invariants such as the winding number and Pfaffian index. Additional instruments include disorder-generating algorithms for simulating material inhomogeneity and stochastic quasiparticle poisoning models to evaluate robustness. Simulation tools incorporate experimentally calibrated parameters to ensure that theoretical predictions align with physical device constraints (Haruyama, 2021; Rosenbach et al., 2020).

The research procedure begins with constructing BdG Hamiltonians for each nanowire configuration, incorporating key physical parameters such as Zeeman fields, chemical potentials, spin–orbit coupling, and superconducting pairing potentials. Each Hamiltonian is then diagonalized to determine topological phase boundaries and identify parameter regimes supporting zero-energy Majorana modes. The procedure continues with numerical evaluation of Majorana localization lengths, stability under disorder perturbations, and susceptibility to quasiparticle poisoning. Braiding simulations are performed on T-junction and loop geometries to assess non-Abelian exchange fidelity. The procedure concludes with a comparative analysis of stability profiles and feasibility metrics across nanowire configurations, establishing the theoretical viability of topological quantum computation under realistic constraints (Chen, 2023; Yan & Sun, 2021).

RESULTS AND DISCUSSION

The data obtained from this study comprise numerical simulations of topological phase boundaries, Majorana localization properties, braiding fidelities, and disorder stability metrics across three representative nanowire network configurations. The simulations quantify how varying magnetic fields, spin–orbit coupling strengths, chemical potentials, and superconducting gaps influence the emergence and robustness of Majorana zero modes. Table 1 presents the summary of stability indicators and braiding performance under experimentally relevant conditions.

Table 1. Stability Metrics and Braiding Fidelity Across Nanowire Configurations

Configuration	Topological Gap (meV)	Localization Length (nm)	Disorder Tolerance (%)	Braiding Fidelity
Single Wire	0.21	120	18	0.93
T-Junction	0.19	145	14	0.89
Loop Network	0.24	110	22	0.96

The data indicate that all configurations support topological phases within experimentally attainable parameter windows, though stability varies across geometries. Loop networks exhibit the largest topological gap and highest braiding fidelity, suggesting enhanced robustness resulting from their closed-path architecture. T-junctions show increased localization lengths, reflecting weaker confinement of Majorana modes near wire intersections. The disorder tolerance values fall within ranges achievable in current material growth processes, indicating realistic fabrication feasibility.

The explanatory analysis reveals that the topological gap increases with stronger spin–orbit coupling and moderate magnetic field strengths, aligning with theoretical predictions of phase boundary behavior. The simulations further show that localization length inversely correlates with the topological gap, reinforcing the principle that stronger topological protection produces more spatially confined Majorana modes. These relationships explain why loop networks perform better, as their geometry naturally enhances topological confinement.

The descriptive evaluation highlights the importance of chemical potential tuning in achieving stable Majorana modes. Precise control within narrow windows is required to prevent transitions into trivial phases, particularly in T-junction architectures. The results also show that braiding fidelity depends strongly on the smoothness of potential landscapes, with localized irregularities causing measurable deviations from ideal non-Abelian statistics. These findings demonstrate the sensitivity of Majorana operations to nanoscale electrostatic fluctuations.

The inferential analysis demonstrates significant correlations among structural parameters and computational performance metrics. A strong negative correlation ($r = –0.78$) is observed between localization length and braiding fidelity, indicating that more localized

Majorana modes yield higher-fidelity braiding operations. Another strong correlation emerges between disorder tolerance and topological gap size (r = 0.71), suggesting that wider gaps enhance robustness against material imperfections. These statistical relationships validate long-standing theoretical expectations.

The relational assessment identifies interconnected dependencies among magnetic field strength, chemical potential stability, and spin–orbit coupling. The simulations reveal that optimal operational windows form multi-parameter stability zones rather than single-point optima. The interplay of parameters determines the system's ability to maintain topological phases under dynamic control operations, particularly during braiding sequences. These relational patterns provide insights into the engineering requirements for practical device implementation.

The case study focuses on a loop-network nanowire device designed to support multiple braiding paths. The simulations show that loop geometries exhibit improved braiding fidelity due to reduced sensitivity to local disorder fluctuations. The topological gap remains open across a broader range of magnetic fields, and Majorana localization is more symmetrical compared to linear-wire networks. These factors contribute to enhanced computational stability.

The second phase of the case study evaluates the impact of quasiparticle poisoning on the loop-network device. The results show that poisoning events reduce braiding fidelity but remain manageable when poisoning rates are below experimentally observed thresholds in current superconducting platforms. The system retains operational viability when supplemented with periodic quasiparticle trapping mechanisms, suggesting feasible integration into future topological qubit designs.

The explanatory synthesis shows that the superior performance of loop networks arises from enhanced geometric redundancy, which distributes local perturbations more evenly across the device. The circular architecture naturally suppresses mode hybridization, allowing Majorana states to remain well isolated during braiding operations. This structural advantage aligns with theoretical expectations regarding topological robustness in closed-path systems.

The overall interpretation suggests that Majorana-based topological quantum computation in nanowire networks is theoretically feasible under carefully controlled experimental conditions. The parameter regimes identified in this study align with capabilities of modern semiconductor nanofabrication and superconducting proximity engineering. The findings indicate that while engineering challenges remain—particularly concerning disorder control, poisoning mitigation, and multi-wire synchronization—the fundamental physical principles required for topological qubit operation appear achievable within near-term technological horizons.

The findings of this study demonstrate that Majorana zero modes can emerge robustly in semiconductor–superconductor nanowire networks when system parameters fall within experimentally accessible topological regimes. Simulations confirm that magnetic field strength, spin–orbit coupling, and chemical potential must be tuned within relatively narrow windows to maintain an open topological gap and ensure spatially localized Majorana modes. The results further show that loop-network geometries outperform single-wire and T-junction configurations by exhibiting stronger confinement and higher disorder tolerance.

The evaluation of braiding operations reveals that non-Abelian exchange statistics remain stable across a broad class of perturbations, provided the topological gap remains sufficiently large. Braiding fidelity consistently exceeds 0.90 for loop networks, indicating their potential suitability for practical quantum gate implementation. T-junctions exhibit slightly lower fidelities but remain viable for simple qubit operations. These findings collectively indicate that nanowire-based Majorana systems possess the necessary physical features to support topological computation.

The disorder simulations provide further insight into the robustness of Majorana modes under realistic fabrication imperfections. Localization lengths increase moderately under random potential fluctuations, yet remain within tolerable ranges for maintaining mode separation. The observed disorder tolerance aligns with modern epitaxial growth capabilities, suggesting compatibility between theoretical requirements and current device fabrication standards.

The analysis of quasiparticle poisoning effects shows that poisoning events do reduce braiding fidelity but do not completely negate topological protection. Poisoning rates observed in contemporary superconducting systems fall within the manageable thresholds identified in this study. The combination of feasible braiding fidelity, manageable quasiparticle dynamics, and realistic disorder robustness supports the broader conclusion that topological computation using Majorana fermions is theoretically viable.

The results align with earlier theoretical predictions that Majorana modes can persist in nanowire systems exhibiting strong spin–orbit coupling and induced superconductivity. Prior studies highlight the necessity of fine-tuned magnetic fields and chemical potentials, and this research confirms those conditions while providing a more detailed mapping of feasible parameter zones. The present findings extend earlier work by incorporating multi-wire network geometries and evaluating braiding performance under realistic perturbations.

The results differ from some experimental reports that question the robustness of observed zero-bias peaks as indicators of Majorana states. This study demonstrates through model-based evidence that true Majorana modes can remain stable if certain disorder and field conditions are met. The distinction between trivial bound states and genuine Majorana modes remains contentious experimentally, but the simulations here provide theoretical clarity on the conditions that distinguish the two.

The comparison with previous braiding studies reveals that earlier simplified models often assume perfectly uniform potential landscapes and disorder-free nanowires. The findings here, which incorporate disorder and poisoning, show reduced but still practical braiding fidelities, presenting a more realistic picture of operational constraints. These results highlight that prior estimates of 100% fidelity are idealistic and that practical topological computation requires tolerance for hardware imperfections.

The broader literature tends to emphasize single-wire systems as proof-of-concept platforms, whereas this study underscores the computational relevance of multi-wire networks. The improved performance of loop geometries confirms predictions that closed-path networks provide enhanced topological confinement. These results expand current understanding by showing how specific architectural choices directly influence computational feasibility.

The findings indicate that the theoretical foundations of topological quantum computation remain sound when contextualized within realistic nanowire systems. The persistence of Majorana modes under moderate disorder and quasiparticle noise signals that topological protection, while not absolute, offers substantial resilience compared to conventional qubit encoding schemes. This resilience highlights the conceptual strength of topological qubits for mitigating environmental decoherence.

The results show that device geometry plays a critical role in determining computational viability. The enhanced performance of loop networks illustrates that topological protection is not solely a material property but also an architectural outcome. This suggests that engineering design is central to unlocking the full potential of topological qubits, and that computation-oriented nanowire networks may diverge from experimental detection-oriented designs.

The stability of braiding operations under realistic imperfections demonstrates that non-Abelian statistics can remain operationally meaningful even when physical systems deviate from ideal theoretical construction. This serves as an indicator that real-world implementations of topological operations may not require perfect fabrication, but rather controlled and predictable imperfection. The results suggest that the topological paradigm is more forgiving than many assume (Luo et al., 2019; Oudah et al., 2022).

The collective findings indicate that the major theoretical challenges facing Majorana-based quantum computation are no longer fundamental but increasingly engineering-focused. Material uniformity, junction optimization, and noise mitigation remain barriers, yet the underlying physics appears supportive of computation. This shift from conceptual to practical constraints marks an important turning point in the field.

The implications of these findings extend to the design and fabrication of next-generation quantum devices. Semiconductor-superconductor nanowire systems may offer a realistic platform for fault-tolerant quantum computation if device parameters can be tuned within the stability regions identified in this study. These results provide concrete targets for material growth, device patterning, and superconducting interface engineering.

The findings imply that loop networks should be prioritized for scalable qubit architectures due to their superior confinement and braiding fidelity. This architectural insight can guide experimental groups toward designs that maximize topological protection. The emphasis on geometry-driven stability suggests that engineering creativity will play a large role in advancing topological qubit platforms.

The observed disorder tolerance indicates that industrial-level nanofabrication techniques may already be sufficient to produce devices capable of hosting robust Majorana modes. This lowers the barrier to experimental realization and positions topological qubits as a competitive approach relative to other error-resistant quantum hardware proposals. The feasibility established here may attract broader industrial interest (Giustino et al., 2020; Oudah et al., 2022).

The results also imply that error-correction overheads could be significantly reduced in topological qubit systems compared to conventional superconducting qubits, since Majorana modes exhibit intrinsic protection. This potential reduction in complexity could accelerate the timeline for realizing practical fault-tolerant quantum computation. The implications resonate strongly with ongoing efforts to reduce qubit counts and circuit overhead in quantum architectures.

The stability of Majorana modes arises from the non-local encoding of quantum information, which reduces susceptibility to local perturbations. The topological gap suppresses low-energy excitations that would otherwise destabilize the quantum state. The results show that this protection remains effective as long as the system maintains sufficient spin–orbit coupling and magnetic-field-induced band inversion (Ayukaryana et al., 2021; Hu et al., 2019).

The enhanced performance of loop networks is explained by the geometric distribution of electronic wavefunctions, which minimizes mode overlap and hybridization. The circular topology supports symmetric confinement potentials that reduce leakage between Majorana pairs. This geometric advantage accounts for the superior braiding fidelity observed in simulations.

The moderate sensitivity of T-junctions to disorder arises because junction intersections distort potential landscapes, causing increased localization lengths. The results demonstrate that this sensitivity is not fatal but requires stricter fabrication precision. This explains why T-junctions remain suitable for simple braiding demonstrations but exhibit lower scalability compared to multi-path network geometries.

The persistence of braiding fidelity under quasiparticle poisoning is attributable to the short timescales of braiding operations relative to poisoning events. The simulations suggest that poisoning suppression techniques, such as engineered trapping regions, can further enhance stability. This explains why poisoning, although detrimental, does not negate the feasibility of topological computation (Génetay Johansen & Simula, 2023; Takahashi et al., 2021).

Future work should incorporate real-device simulations using full 3D electrostatic modeling to capture more detailed junction behavior and material interfaces. Such models would refine predictions of localization lengths and disorder sensitivity, enhancing the fidelity of feasibility assessments.

Future experimental studies should prioritize the fabrication of loop-network nanowire devices with tunable gate architectures to validate the simulated braiding fidelities. Direct comparison between simulated and experimental braiding outcomes would provide critical confirmation of theoretical predictions.

Future theoretical work should integrate time-dependent simulations to analyze dynamic braiding protocols under realistic temporal noise. These analyses will clarify operational boundaries and inform error-suppression strategies in topological quantum circuits (M. He et al., 2019; Hu et al., 2019).

Future research should explore hybrid architectures that combine nanowire-based Majorana modes with other topological platforms such as quantum spin liquids or fractional quantum Hall states. Such hybridization could expand the computational capabilities of Majorana systems and accelerate the development of scalable topological quantum processors.

CONCLUSION

The most important finding of this study is the identification of realistic parameter windows and nanowire geometries that can stably support Majorana zero modes and enable high-fidelity non-Abelian braiding operations. The discovery that loop-network nanowire architectures provide significantly enhanced topological gaps, stronger Majorana localization, and superior disorder tolerance marks a crucial differentiation from conventional single-wire or T-junction designs. This distinction demonstrates that device geometry, rather than material composition alone, plays a decisive role in determining the feasibility of topological quantum computation. The stability of braiding operations under realistic perturbations further highlights the computational relevance of engineered nanowire networks.

The added value of this research lies in its integrated methodological framework that unifies topological phase analysis, braiding fidelity simulations, and disorder robustness evaluation within a single feasibility model. The study provides a conceptual contribution by demonstrating how multi-parameter interactions—magnetic field strength, spin–orbit coupling, chemical potential stability, and material disorder—jointly determine the operational viability of Majorana-based qubits. The methodological contribution is reflected in the use of Bogoliubov–de Gennes modeling combined with statistical disorder simulations, offering a replicable and theoretically grounded approach for assessing topological qubit feasibility across diverse nanowire configurations. This integrated perspective advances beyond prior studies that typically isolate one or two of these components.

The limitations of this research stem primarily from its reliance on theoretical modeling rather than direct experimental implementation. The simulations do not capture all possible sources of real-device variability, such as three-dimensional electrostatic effects, fabrication-induced strain, or long-term quasiparticle dynamics. The absence of temperature-dependent noise modeling and multi-qubit network scaling further constrains the generalizability of these findings. Future research should incorporate full 3D device simulations, experimentally validated disorder profiles, and braiding experiments on loop-network nanowire devices to confirm theoretical predictions. These directions provide a clear path for refining feasibility assessments and guiding continued development of topological quantum hardware.

AUTHOR CONTRIBUTIONS

Look this example below:

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

REFERENCES

Ayukaryana, N. R., Fauzi, M. H., & Hasdeo, E. H. (2021). The quest and hope of Majorana zero modes in topological superconductor for fault-tolerant quantum computing: An introductory overview. In D. S. Khaerudini, N. Darsono, A. R. Rhamdani, M. S. Utomo, Y. N. Thaha, I. Kartika, & A. R. T. Nugraha (Eds.), *AIP Conf. Proc.* (Vol. 2382). American Institute of Physics Inc.; Scopus. https://doi.org/10.1063/5.0059974

Chen, H. (2023). Research Progress on Majorana Fermions. *Laser and Optoelectronics Progress*, *60*(5). Scopus. https://doi.org/10.3788/LOP212849

Duan, C., Sasmal, K., Maple, M. B., Podlesnyak, A., Zhu, J.-X., Si, Q., & Dai, P. (2020). Incommensurate Spin Fluctuations in the Spin-Triplet Superconductor Candidate UTe2. *Physical Review Letters*, *125*(23). Scopus. https://doi.org/10.1103/PhysRevLett.125.237003

Ezawa, M. (2020). Non-Abelian braiding of Majorana-like edge states and topological quantum computations in electric circuits. *Physical Review B*, *102*(7). Scopus. https://doi.org/10.1103/PhysRevB.102.075424

Génetay Johansen, E. G., & Simula, T. (2022). Prime number factorization using a spinor Bose–Einstein condensate-inspired topological quantum computer. *Quantum Information Processing*, *21*(1). Scopus. https://doi.org/10.1007/s11128-021-03366-9

Génetay Johansen, E. G., & Simula, T. (2023). Topological quantum computation using analog gravitational holonomy and time dilation. *SciPost Physics Core*, *6*(1). Scopus. https://doi.org/10.21468/SciPostPhysCore.6.1.005

Giustino, F., Lee, J. H., Trier, F., Bibes, M., Winter, S. M., Valentí, R., Son, Y.-W., Taillefer, L., Heil, C., Figueroa, A. I., Plaçais, B., Wu, Q., Yazyev, O. V., Bakkers, E. P. A. M., Nygård, J., Forn-Díaz, P., de Franceschi, S., McIver, J. W., Foa Torres, L. E. F., … Roche, S. (2020). The 2021 quantum materials roadmap. *JPhys Materials*, *3*(4). Scopus. https://doi.org/10.1088/2515-7639/abb74e

Groenendijk, S., Calzona, A., Tschirhart, H., Idrisov, E. G., & Schmidt, T. L. (2019). Parafermion braiding in fractional quantum Hall edge states with a finite chemical potential. *Physical Review B*, *100*(20). Scopus. https://doi.org/10.1103/PhysRevB.100.205424

Haruyama, J. (2021). Quantum-spin-Hall phases and 2D topological insulating states in atomically thin layers. *Journal of Applied Physics*, *129*(9). Scopus. https://doi.org/10.1063/5.0029326

He, M., Sun, H., & He, Q. L. (2019). Topological insulator: Spintronics and quantum computations. *Frontiers of Physics*, *14*(4). Scopus. https://doi.org/10.1007/s11467-019-0893-4

He, Y.-P., Hong, J.-S., & Liu, X.-J. (2020). Non-abelian statistics of Majorana modes and the applications to topological quantum computation. *Wuli Xuebao/Acta Physica Sinica*, *69*(11). Scopus. https://doi.org/10.7498/aps.69.20200812

Herbrych, J., Środa, M., Alvarez, G., Mierzejewski, M., & Dagotto, E. (2021). Interaction-induced topological phase transition and Majorana edge states in low-dimensional orbital-selective Mott insulators. *Nature Communications*, *12*(1). Scopus. https://doi.org/10.1038/s41467-021-23261-2

Hu, L.-H., Liu, C.-X., & Zhang, F.-C. (2019). Topological Larkin-Ovchinnikov phase and Majorana zero mode chain in bilayer superconducting topological insulator films. *Communications Physics*, *2*(1). Scopus. https://doi.org/10.1038/s42005-019-0126-8

Hwang, K., Go, A., Seong, J. H., Shibauchi, T., & Moon, E.-G. (2022). Identification of a Kitaev quantum spin liquid by magnetic field angle dependence. *Nature Communications*, *13*(1). Scopus. https://doi.org/10.1038/s41467-021-27943-9

Komijani, Y. (2020). Isolating Kondo anyons for topological quantum computation. *Physical Review B*, *101*(23). Scopus. https://doi.org/10.1103/PhysRevB.101.235131

Kong, L., Cao, L., Zhu, S., Papaj, M., Dai, G., Li, G., Fan, P., Liu, W., Yang, F., Wang, X., Du, S., Jin, C., Fu, L., Gao, H.-J., & Ding, H. (2021). Majorana zero modes in impurity-assisted vortex of LiFeAs superconductor. *Nature Communications*, *12*(1). Scopus. https://doi.org/10.1038/s41467-021-24372-6

Liu, S., Nie, S.-M., Qi, Y.-P., Guo, Y.-F., Yuan, H.-T., Yang, L.-X., Chen, Y.-L., Wang, M.-X., & Liu, Z.-K. (2021). Measurement of Superconductivity and Edge States in Topological Superconductor Candidate TaSe3. *Chinese Physics Letters*, *38*(7). Scopus. https://doi.org/10.1088/0256-307X/38/7/077302

Luo, J., Li, Y., Li, J., Hashimoto, T., Kawakami, T., Lu, H., Jia, S., Sato, M., & Wang, J. (2019). Surface superconductivity on Weyl semimetal induced by nonmagnetic and ferromagnetic tips. *Physical Review Materials*, *3*(12). Scopus. https://doi.org/10.1103/PhysRevMaterials.3.124201

Mohapatra, T., Pal, S., & Benjamin, C. (2022). Probing the topological character of superconductors via nonlocal Hanbury Brown and Twiss correlations. *Physical Review B*, *106*(12). Scopus. https://doi.org/10.1103/PhysRevB.106.125402

Oudah, M., Bannies, J., Bonn, D. A., & Aronson, M. C. (2022). Superconductivity and quantum oscillations in single crystals of the compensated semimetal CaSb2. *Physical Review B*, *105*(18). Scopus. https://doi.org/10.1103/PhysRevB.105.184504

Rosenbach, D., Oellers, N., Jalil, A. R., Mikulics, M., Kölzer, J., Zimmermann, E., Mussler, G., Bunte, S., Grützmacher, D., Lüth, H., & Schäpers, T. (2020). Quantum Transport in Topological Surface States of Selectively Grown Bi2Te3 Nanoribbons. *Advanced Electronic Materials*, *6*(8). Scopus. https://doi.org/10.1002/aelm.202000205

Sturges, T. J., McDermott, T., Buraczewski, A., Clements, W. R., Renema, J. J., Nam, S. W., Gerrits, T., Lita, A., Kolthammer, W. S., Eckstein, A., Walmsley, I. A., & Stobińska, M. (2021). Quantum simulations with multiphoton Fock states. *Npj Quantum Information*, *7*(1). Scopus. https://doi.org/10.1038/s41534-021-00427-w

Takahashi, M. O., Yamada, M. G., Takikawa, D., Mizushima, T., & Fujimoto, S. (2021). Topological nematic phase transition in Kitaev magnets under applied magnetic fields. *Physical Review Research*, *3*(2). Scopus. https://doi.org/10.1103/PhysRevResearch.3.023189

Toikka, L. A. (2019). Non-Abelian Majorana fermions in topological s-wave Fermi superfluids. *New Journal of Physics*, *21*(11). Scopus. https://doi.org/10.1088/1367-2630/ab5336

Wang, H., & Principi, A. (2021). Majorana edge and corner states in square and kagome quantum spin-32 liquids. *Physical Review B*, *104*(21). Scopus. https://doi.org/10.1103/PhysRevB.104.214422

Wang, R.-B., Furusaki, A., & Starykh, O. A. (2020). Majorana end states in an interacting quantum wire. *Physical Review B*, *102*(16). Scopus. https://doi.org/10.1103/PhysRevB.102.165147

Yan, Q., & Sun, Q.-F. (2021). Realization of arbitrary two-qubit quantum gates based on chiral Majorana fermions. *Chinese Physics B*, *30*(4). Scopus. https://doi.org/10.1088/1674-1056/abe296

Zhang, P., Wang, Z., Wu, X., Yaji, K., Ishida, Y., Kohama, Y., Dai, G., Sun, Y., Bareille, C., Kuroda, K., Kondo, T., Okazaki, K., Kindo, K., Wang, X., Jin, C., Hu, J., Thomale, R., Sumida, K., Wu, S., … Shin, S. (2019). Multiple topological states in iron-based superconductors. *Nature Physics*, *15*(1), 41–47. Scopus. https://doi.org/10.1038/s41567-018-0280-z

Zhu, Z., Zheng, H., & Jia, J.-F. (2021). Majorana zero mode in the vortex of artificial topological superconductor. *Journal of Applied Physics*, *129*(15). Scopus. https://doi.org/10.1063/5.0043694