Qeios

Peer Review

Review of: "A Review of Formal Methods in Quantum Circuit Verification"

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Overall, this manuscript provides a timely and well-organized survey of formal methods for quantum circuit verification. The paper covers multiple important verification paradigms and gives readers a clear sense of why verification is becoming essential as quantum computing moves toward more practical and safety-sensitive use cases. In its current form, the work is promising and has the potential to be a useful reference for both new and experienced researchers in the area. For these reasons, my overall recommendation is “Accept with Major Revision,” since several claims and comparisons need stronger grounding and clearer qualification to meet the standards expected of a high-quality review paper.

The paper is generally clear and readable, with a logical flow between sections and accessible explanations of key ideas. The writing style is mostly consistent, and the sections are structured in a way that makes it easy to follow the progression from foundational techniques to applications, challenges, and future directions. The introduction sets the context effectively and motivates the need for verification in quantum computing. In addition, the background coverage is reasonable and provides a good starting point for readers who may not be specialists in all of the methods discussed. Overall, the manuscript does a good job of presenting the main concepts in a coherent narrative and maintaining a professional tone.

That said, I believe the following issues should be addressed to strengthen the paper substantially.

1. Some claims are broad without concrete evidence or detail

Phrases such as “successfully used,” “tested different classes,” and “good scalability” are not supported with brief quantitative outcomes, example metrics, or sufficiently specific citations in the surrounding discussion. Adding concrete evidence, even in concise form, would improve credibility and strengthen the results and interpretation aspects of the review.

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2. Probabilistic guarantees are mentioned but not characterized

Terms like “high probability” remain vague. The review would benefit from explicitly stating what types of probabilistic guarantees are provided in scenario-based approaches, including confidence or failure probability, key assumptions, and how sampling complexity affects the strength of the guarantee. Without this, the method can appear more definitive than it is.

3. Overstates complexity and scalability without qualifying assumptions

Claims implying “polynomial time scalability” alongside soundness are too strong unless the paper clarifies the scope, such as the abstract domains used, which properties are checked, and what precision tradeoffs are made. These statements should be qualified carefully to avoid unintended inaccuracy.

4. Scalability discussion is generic and not supported by evidence

The model checking discussion notes “varying levels of success” for symbolic approaches but does not indicate what success means in practical terms, for example, typical qubit limits, circuit families, runtime, or memory behavior. Including representative numbers and comparisons would strengthen the review’s usefulness and interpretability.

5. Some claims use strong language without support

Phrases such as “catastrophic failures,” “rigorously guarantee,” or broad suitability statements would be stronger if supported with citations and context, or else softened to reflect realistic limits. In a review paper, precision in phrasing is important to avoid overstating maturity or capability.

6. Challenges section is generic and does not quantify tradeoffs

While the challenges are directionally correct, the discussion remains high-level. The paper would be improved by explaining tradeoffs more concretely, including what is lost when abstraction is introduced, where modular verification breaks down, and what symbolic methods compress well versus poorly. Even a short comparative summary would increase depth.

7. Optional but potentially valuable improvements

It would strengthen the scope to include at least one solid reference on assertion-based approaches (maybe in the QEC section). In addition, ternary logic has appeared in quantum-related work and should be at least briefly mentioned as part of the broader verification and specification landscape.

Check this:

https://ieeexplore.ieee.org/abstract/document/10821299

Thank you for the work put into this manuscript. Please note that the phrases mentioned above were only a few examples to draw attention to this issue. You may consider reviewing all strong or broad claims throughout the manuscript to ensure they are not stated without concrete evidence, sufficient detail, or appropriate citations. With the above revisions, especially improved evidence, clearer qualification of claims, and stronger cross-method comparisons, the paper can become a more rigorous and reliable reference. I look forward to seeing a revised version that addresses these points and further improves the overall quality and impact of the review.

Declarations

Potential competing interests: No potential competing interests to declare.