Appendix A Selected articles

This appendix contains the table that summons the identification numbers, titles and references of the articles encountered. We can also observe the selected as primary studies, as they are indicated with an * next to their identification number.

Table 6: Articles encountered after performing the first search.

ID	Title	Reference
*1	A Taxonomic View of the Fundamental Concepts of Quantum Computing–A Software Engineering Perspective	[58]
*2	Cloning and Beyond: A Quantum Solution to Duplicate Code	[53]
*3	Making existing software quantum safe: A case study on IBM Db2	[154]
*4	Hybrid Multi-Objective Genetic Programming for Parameterized Quantum Operator Discovery	[43]
*5	QUANTUMOONLIGHT: A low-code platform to experiment with quantum machine learning	[9]
6	Towards Quantum-algorithms-as-a-service	[28]
*7	Quantum computing for software engineering: prospects	[85]
8	QAI4ASE: Quantum artificial intelligence for automotive software engineering	[29]
9	Quantum computing challenges in the software industry. A fuzzy AHP-based approach	[16]
10	A synergic quantum particle swarm optimisation for constrained combinatorial test generation	[48]
11	Towards Higher-Level Abstractions for Quantum Computing	[27]
12	Photonics Applications and Web Engineering - WILGA 2022	[112]
13	1-2-3 Reproducibility for Quantum Software Experiments	[81]
*14	Reversible multiplier with a column-wise structure and a reduced number of ancilla inputs and garbage outputs	[118]
15	Function translations and search-based transformation for MVL reversible circuit synthesis	[83]
*16	Optimality Study of Existing Quantum Computing Layout Synthesis Tools	[128]
17	Quantum-like Gaussian mixture model	[139]
*18	On the definition of quantum programming modules	[127]
*19	Experimental Implementation of Discrete Time Quantum Walk with the IBM Qiskit Library	[6]
*20	Identifying Bug Patterns in Quantum Programs	[158]
*21	Infrastructure to Enable Controlled Quantum Software Testing and Debugging Experiments	[24]
*22	Some Size and Structure Metrics for Quantum Software	[156]
23	A hybrid adaptive quantum behaved particle swarm optimization algorithm based multilevel thresholding for image segmentation	[135]
24	Advanced Application of Nanotechnology in Engineering	[121]
25	Understanding Quantum Software Engineering Challenges An Empirical Study on Stack Exchange Forums and GitHub Issues	[33]
*26	Non-functional requirements for quantum programs	[115]
27	Monadic classes of quantum B-algebras	[26]
28	The Parallel Quantum Algorithm for the Class of Optimization	[145]
*29	The Quantum software lifecycle	[138]
*30	Quantum Software Engineering Supremacy in Intelligent Robotics	[67]
*31	Lasso Regression with Quantum Whale Optimization Algorithm	[74]
*32	Stochastic Neighbor Embedding Algorithm Based on Quantum Genetic Algorithm with Gaussian Parameters	[123]
33	Decision-making in cognitive paradoxes with contextuality and quantum formalism	[52]
34	Sustainability in Migrating Workloads to Public Clouds	[94]
35	Violation of CHSH inequality and marginal laws in mixed sequential measurements with order effects	[116]
36	Software engineering for 'quantum advantage'	[20]

*37	Insights on Training Neural Networks for QUBO Tasks	[39]
38	The Holy Grail of Quantum Artificial Intelligence: Major Challenges in Accelerating the Machine Learning Pipeline	[40]
*39	Quantum enhanced machine learning: An overview	[30]
40	A tool for quantum software evolution	[54]
*41	Off-the-shelf components for quantum programming and testing	[46]
42	Using quantum probability for word embedding problem	[130]
*43	Quantum algorithms for near-term devices	[141]
44	Reengineering of information systems toward classical-quantum systems	[96]
45	Adapting service delivery for quantum programming	[57]
*46	Quantum machine learning: Benefits and practical examples	[99]
47	The Talavera manifesto for quantum software engineering and programming	[100]
48	Performance Comparison of Population-Based Quantum-Inspired Evolutionary Algorithms	[150]
49	A verifiable threshold secret sharing scheme based on lattices	[108]
*50	On an explicit representation of the Łukasiewicz sum as a quantum operation	[50]
*51	On testing quantum programs	[84]
52	Research of Long-Distance Encrypted Signal Transmission Enhancement Method Based on Quantum Communication Power System	[151]
*53	Toward automatic verification of quantum programs	[152]
54	On the performance analysis of Sphincs+verification	[60]
55	CloudGanga: Cloud computing based SDI model for ganga river basin management in India	[21]
56	Performance evaluation of quantum ESPRESSO on NEC SX-ACE	[137]
57	A bisectional multivariate quadratic equation system for RFID anti-counterfeiting	[159]
58	From excavations to web: A gis for archaeology	[31]
59	Improved treatment of exact exchange in Quantum ESPRESSO	[22]
60	Quantum music	[106]
61	Principals of simulation of ultrafast charge transfer in solution within the multichannel stochastic point-transition model	[89]
62	Open source molecular modeling	[102]
63	Comparing the performance of quantum-inspired evolutionary algorithms for the solution of software requirements selection problem	[70]
64	A comprehensive literature review of asymmetric key cryptography algorithms for establishment of the existing gap	[42]
65	Design of a modulus based Round Robin scheduling algorithm	[12]
66	A search for quantum coin-flipping protocols using optimization techniques	[88]
67	Development of WebGIS framework for Indian technical institutes using open source GIS tools	[114]
68	The research of adaptive beam forming algorithm based on QPSO and antenna array	[101]
69	Queueing theory study of round robin versus priority dynamic quantum time round robin scheduling algorithms	[86]
70	Developing a high-performance quantum chemistry program with a dynamic scripting language	[119]
71	Accelerator circuits for quantum simulation	[65]
72	Prediction approach of software fault-proneness based on hybrid artificial neural network and quantum particle swarm optimization	[55]
73	Advance quantum based binary neural network learning algorithm	[93]
74	Develop direct geo-referencing system based on open source software and hardware platform	[75]
75	Insight into the operation of NTRU and a comparative study of NTRU, RSA and ECC public key cryptosystems	[41]
76	An Extreme Learning Machine based on Quantum Particle Swarm Optimization and its application in handwritten numeral recognition	[125]
77	Quantifying urban sprawl with spatial autocorrelation techniques using multi-temporal satellite data	[91]

78	Analysis on light quantity and quality based on diverse cloud conditions	[146]
79	Ecological niche modeling using Satellite Data for assessing distribution of threatened species Ceropegia bulbosa Roxb	[69]
80	Development and comparison of Open Source based web GIS frameworks on WAMP and Apache Tomcat web servers	[8]
81	Requirement analysis and metric development for public participatory GIS	[109]
82	Analysis and acceleration of NTRU lattice-based cryptographic system	[18]
83	The information reconciliation protocol basing on error codes	[90]
84	Bone drilling methodology and tool based on position measurements	[32]
*85	Quantum searching application in search based software engineering	[143]
86	Simulation of quantum error correction by means of QuantumCircuit package	[44]
87	Dimensionality reduction based on the classifier models: Performance Issues in the prediction of Lung cancer	[19]
88	Software requirements selection using Quantum-inspired multi-objective differential evolution algorithm	[71]
89	A high-level fortran interface to parallel matrix algebra	[111]
90	Formulas and algorithms for quantum differentiation of quantum Bernstein bases and quantum Bézier curves based on quantum blossoming	[45]
91	An implementation of compact genetic algorithm on a quantum computer	[153]
92	A modified QIEA for strongly correlated knapsack problems	[155]
93	User friendly open GIS tool for large scale data assimilation - A case study of hydrological modelling	[49]
94	The ETSF: An e-infrastructure that bridges simulations and experiments	[80]
95	Developing algorithms and software for the parallel solution of the symmetric eigenvalue problem	[15]
96	CLS QTM: New model of node configuration in collaboration learning systems by quantum turing machine	[17]
97	Passive monitoring method for analysis Quantum Key Distribution performance statistics	[95]
98	Wave probabilistic information power	[126]
*99	New results on quantum property testing	[25]
100	Quantum-inspired evolutionary algorithms applied to numerical optimization problems	[5]
101	A quantum genetic algorithm based QoS routing protocol for wireless sensor networks	[77]
102	Towards software test data generation using discrete quantum particle swarm optimization	[7]
103	Object construction and destruction design patterns in Fortran 2003	[113]
104	Seamless long term learning in agile teams for sustainable leadership	[107]
105	The impact of test case reduction and prioritization on software testing effectiveness	[132]
*106	A quantum algorithm for software engineering search	[51]
107	Checking the consistency between ucm and psm using a graph-based method	[131]
108	Schedulability analysis on generalized quantum-based fixed priority scheduling	[92]
109	The Matrix Model of Computation	[103]
110	Applications of the matrix model of computation	[104]
111	Quantum-inspired immune memory algorithm for self-structuring antenna optimization	[144]
112	Improved quantum-inspired evolutionary algorithm and its application to 3-SAT problems	[36]
113	Quantum approximation on some classes of multivariate functions	[148]
114	An application of BPEL for service orchestration in an industrial environment	[105]
115	A Study on design for testability in component-based embedded software	[61]
116	Semantics-based component repository: Current state of arts and a calculation rating factor-based framework	[72]
117	Quantum-behaved particle swarm optimization with chaotic search	[147]
118	A game for taking requirements engineering more seriously	[66]
119	A component approach to collaborative scientific software development: Tools and techniques utilized by the Quantum Chemistry Science Application Partnership	[63]
120	Improving service selection in component-based architectures with optimal stopping	[122]

121	Guiding component-based hardware/software co-verification with patterns	[73]
*122	A formal derivation of Grover's quantum search algorithm	[160]
123	Component architectures for quantum chemistry: Forging new capabilities and insights	[62]
124	A rapid computer algorithm for the HAEUAV route planning	[149]
125	The contribution of free software to software evolution	[23]
126	First-principles computation of material properties: The ABINIT software project	[47]
127	On cognitive informatics	[136]
128	Characterization/test software for high density IR focal planes	[134]
129	Learnable evolution model: evolutionary processes guided by machine learning	[82]
130	Computational chemistry on Fujitsu vector-parallel processors: Development and performance of applications software	[110]
131	Engineering automation for computer based systems	[78]
132	Generating functional design verification tests	[124]
133	Quantum Improvements	[14]
134	Implementation of software reuse: Technical and organizational issues	[68]
135	World wakes up to Java	[38]

Appendix B Tables

This appendix contains the tables that summon the number of times each of the terms appeared in the six different research questions.

Table 7: Quantum algorithms, applications or software solutions mentioned or proposed and the number of times each one of them appeared (counts) in the 27 primary studies for RQ1.

Quantum algorithm, solution or applications	Counts
Grover's algorithm (Grover's quantum search algorithm, Grover's Search Algorithm, Grover's Search Algorithm, Iterative Shallowing Grover Search (ISGS), Iterative Deepening Grover Search - FindAll (IDGS-FA), Grover's inference)	23
Shor's algorithm (factoring integer numbers and discrete logarithms)	23
Quantum machine learning (implemented in quantum for the analysis of quantum data)	10
Quantum Approximate Optimization Algorithm (QAOA)	9
Quantum simulation (quantum systems, direct Hamiltonian simulation, Scalable simulations of quantum systems in physics, simulation of quantum many-body systems)	8
Variational Quantum Eigensolver (VQE)	8
Quantum queries (Quantum query lower bounds for the collision problem and for testing distributions, Quantum query upper bounds for reconstructing distributions, Quantum queries for testing graph isomorphism)	7
Simon's algorithm	7
Quantum genetic algorithm (Genetic search algorithm (QGSA), Reduced quantum genetic algorithm (RQGA))	7
Quantum Search (to check safety properties of finite state machines, Quantum space search in hierarchical structures, unstructured search, Quantum search algorithm (QSA), quantum search to check safety properties of finite state machines)	6
Cryptography	5
Library-based software synthesis problem	4
Quantum neural networks	4
Deutsch-Jozsa's algorithm (Oracle-based)	3
Quantum cloning (Symmetric UQCM (universal quantum cloning machine))	3
Quantum Fourier transform (QFT)	3
Quantum sampling (random quantum circuit)	3
Quantum walk/Quantum random walk (Quantum walk (staggered quantum walk, coined quantum walk, Szegedy quantum walk)	3
Modelling of chemical reactions	3
Bernstein-Vazirani algorithm	2
Find All (FA) problem	2
Fourier checking	2
FSM property checking	2
Large Spaces (LS) problem	2
Linear equations	2
Path-coverage test generation	2
Periodicity testing problem	2
Quantum inference (Quantum-genetic inference, quantum-fuzzy inference (QFI))	2
Quantum information theory	2
Quantum Support Vector Classifier	2
Quantum testing algorithm	2
Sampling problems (Sampling random quantum circuit)	2
Searching a database	2
Software test generation	2
Target Weight Indeterminacy (TWI) problem	2
Quantum chemistry	2
Quadratic unconstrained binary optimization (QUBO)	2
Abrams and Lloyd's algorithm (identification of periodic properties)	1
A modification of a classical lower bound by Lachish and Newman	1
Algebraic applications	1

Algorithm to approximately count the size of certain sets	1
Algorithm to tackle the qubit mapping problem: SABRE	1
BBHT algorithm	1
Black-box problems	1
Boolean satisfiability solvers	1
Collision problem	1
Combinatorial optimization	1
Data fitting	1
Detection and pattern recognition	1
Equation solving	1
Fixed-point quantum search (FPQS)	1
Fuzzy logic	1
Graph applications	1
Hamiltonian problem	1
Harrow–Hassidim–Lloyd	1
Hybrid Helmholtz machine	1
Intelligent robotic control	1
Inverse function computation	1
Learning applications	1
Lukasiewicz sum	1
Mixed-state quantum algorithms (depending on the types of data manipulated)	1
Number-theoretic applications	1
Optimization	1
Oracle problems	1
Property testing	1
Pure-state quantum algorithms (depending on the types of data manipulated)	1
Quantum adiabatic evolution searching algorithm	1
Quantum-based web apps	1
Quantum Boltzmann Machine	1
Quantum data structures (the data is encoded in qubits directly)	1
Quantum-enhanced machine learning (implemented in quantum for the analysis of traditional data)	1
Quantum Hopfield Neural Network (HNN)	1
Quantum learning models (quantum exact learning, quantum probability approximately correct (PAC) learning and quantum agnostic learning)	1
Quantum phase estimation algorithm	1
Quantum utilities	1
Quantum-setting algorithmic counterpart of Wirth's equation	1
Quantum Support Vector Machine	1
Quantum whale optimization algorithm	1
Randomness generation	1
Reversible logic (reversible processing circuits: adders, multipliers)	1
Search or string comparison	1
Systems of differential equations solvers	1
Variational Quantum Regressor	1
Zalka and Wiesner's algorithm	1
Support Network	1
Emotions and sentiment analysis	1
Error correction	1
Quantum internet	1
Navigation	1
Image processing	1
Cloud computing	1
Weather prediction	1
Energy management	1
Transportation	1

Finance	1
Code clone detection	1
Subgraph isomorphism problem	1
Quadratic optimization problem	1
Quadratic Unconstrained Discrete Optimization (QUDO)	1
Graph isomorphism	1
Jop shop scheduling problem	1
Artificial intelligence	1
Medicine	1
Space exploration	1
Cybersecurity	1
Security for encrypted data	1
Quantum key distribution (QKD)	1
Hybrid quantum-classical algorithms	1

Table 8: Responses for RQ1 categorized as quantum algorithms, quantum problems or applications of quantum computing.

Quantum algorithm	
Grover's algorithm	Shor's algorithm
Variational Quantum Eigensolver	Quantum Approximate Optimization Algorithm
Simon's algorithm	Quantum genetic algorithm
Deutsch-Jozsa's algorithm	Quantum Fourier transform
Bernstein-Vazirani algorithm	Quantum Support Vector Classifier
Quantum testing algorithm	Abrams and Lloyd's algorithm
Quantum cloning	Algorithm to approximately count the size of certain sets
Quantum queries	BBHT algorithm
Harrow–Hassidim–Lloyd	Mixed-state quantum algorithms
Pure-state quantum algorithms	Quantum adiabatic evolution searching algorithm
Quantum Boltzmann Machine	Quantum Hopfield Neural Network
Quantum phase estimation algorithm	Quantum-setting algorithmic counterpart of Wirth's equation
Quantum Support Vector Machine	Quantum whale optimization algorithm
Variational Quantum Regressor	Zalka and Wiesner's algorithm
Support Network	Algorithm to tackle the qubit mapping problem: SABRE
Quantum Search	Quantum walk/Quantum random walk
Fixed-point quantum search	A modification of a classical lower bound by Lachish and Newman
Quantum sampling	Quadratic Unconstrained Discrete Optimization
Quantum key distribution	Hybrid quantum-classical algorithms
Application	
Quantum machine learning	Quantum simulation
Quantum neural networks	Cryptography
Fourier checking	FSM property checking
Linear equations	Modelling of chemical reactions
Path-coverage test generation	Quantum inference
Quantum information theory	Searching a database
Software test generation	Algebraic applications
Boolean satisfiability solvers	Combinatorial optimization
Data fitting	Detection and pattern recognition
Equation solving	Fuzzy logic
Graph applications	Hybrid Helmholtz machine
Intelligent robotic control	Inverse function computation
Learning applications	Lukasiewicz sum
Number-theoretic applications	Optimization
Property testing	Quantum-based web apps

Quantum chemistry	Quantum data structures
Quantum-enhanced machine learning	Quantum learning models
Quantum utilities	Quadratic unconstrained binary optimization
Randomness generation	Reversible logic
Search or string comparison	Systems of differential equations solvers
Emotions and sentiment analysis	Error correction
Quantum internet	Navigation
Image processing	Cloud computing
Weather prediction	Energy management
Transportation	Finance
Code clone detection	Graph isomorphism
Artificial intelligence	Medicine
Space exploration	Cybersecurity
Security for encrypted data	
Quantum problems	
Library-based software synthesis problem	Find All (FA) problem
Large Spaces (LS) problem	Periodicity testing problem
Jop shop scheduling problem	Target Weight Indeterminacy (TWI) problem
Black-box problems	Collision problem
Hamiltonian problem	Oracle problems
Subgraph isomorphism problem	Quadratic optimization problem
Sampling problems (Sampling random quantum circuit)	

Table 9: Quantum technologies mentioned or employed and the number of times each one of them appeared (counts) in the 29 primary studies for RQ2.

Quantum technology/language/term	Counts
Quantum circuit	15
Qiskit	11
Quantum gates	11
Adiabatic	7
Q#	6
Gate-based devices	5
Cirq	4
OpenQASM	4
Quantum annealing	4
Trapped ions	4
Circuit	3
t—ket¿	3
Quipper	3
Gate-based superconducting quantum computers	3
Topological quantum computer	3
Quil	2
ProjectQ	2
Superconducting qubits	2
Forest	2
QPL	2
Scaffold	2
LIQUI—¿	2
Silicon	2
Photonic quantum computer	2
Quantum logic gate	1
Measurement-based	1
QSAM	1

Electron pins	1
Superconducting-based quantum computing	1
Ocean	1
Forge	1
Quantum Turing machines	1
Rigetti	1
IonQ	1
Braket	1
Honeywell	1
Q—SI¿	1
qGCL	1
QMASM	1
Silq	1
LQP	1
QFC	1
QML	1

Table 10: Responses for RQ2 categorized as quantum computer types and quantum representation/languages.

<table>
<tr><th colspan="4">Quantum computer types</th></tr>
<tr><th colspan="4">Annealing-based computers</th></tr>
<tr><td colspan="2">Adiabatic</td><td colspan="2">Quantum annealing</td></tr>
<tr><th colspan="4">Gate-based computers</th></tr>
<tr><td colspan="2">Gate-based devices</td><td colspan="2">Topological quantum computer</td></tr>
<tr><td colspan="4">Gate-based superconducting quantum computers</td></tr>
<tr><th colspan="4">Superconducting-based computers</th></tr>
<tr><td colspan="2">Superconducting qubits</td><td colspan="2">Superconducting-based quantum computing</td></tr>
<tr><th colspan="4">Others</th></tr>
<tr><td>Measurement-based</td><td>Trapped ions</td><td>Electron pins</td><td>Quantum Turing machines</td></tr>
<tr><td colspan="4">Photonic quantum computer</td></tr>
<tr><th colspan="4">Quantum representation/languages</th></tr>
<tr><th colspan="4">Gate-based devices related</th></tr>
<tr><td>Quantum circuit</td><td>Quantum gates</td><td>Qiskit</td><td>Q#</td></tr>
<tr><td>Cirq</td><td>OpenQASM</td><td>Circuit</td><td>Quipper</td></tr>
<tr><td>Quantum logic gate</td><td>ProjectQ</td><td>Quil</td><td>QPL</td></tr>
<tr><td>Rigetti</td><td>Braket</td><td>QMASM</td><td>Silq</td></tr>
<tr><th colspan="4">Superconducting qubits related</th></tr>
<tr><td>t|ket></td><td>Forest</td><td>Scafold</td><td>QSAM</td></tr>
<tr><td>Ocean</td><td>Forge</td><td>LIQUI| ></td><td>Silicon</td></tr>
<tr><td>IonQ</td><td>Honeywell</td><td>Qt|SI| ></td><td>qGCL</td></tr>
<tr><td>LQP</td><td>QFC</td><td colspan="2">QML</td></tr>
</table>

Table 11: Terms, parameters or metrics to evaluate quantum software and the number of times each one of them appeared (counts) in the 24 primary studies for RQ3.

Term/parameter/metric	Counts
Performance	10
Speedup	10
Efficiency	5
Accuracy	5
Number of gates	5
Quality	4
Correctness	3

Fault-tolerance	3
Bug evaluation	2
Depth	2
Failure probability	2
Iteration speed	2
Reliability	2
Success	2
Time efficiency	2
Quantum cost	2
Algorithmic quantum cooling	1
Ancilla Reclaiming	1
Architectural design size	1
Asymptotic complexity	1
Circuit size	1
Cohesion	1
Complexity	1
Composability	1
Computational complexity	1
Computational speed	1
Cost effective	1
Cost of failure	1
Coupling	1
Detailed design size	1
Entanglement limitation	1
Error probability	1
Error rate	1
Fast	1
Indistinguishability	1
Information flow (Henry and Kafura)	1
Iteration cost	1
Learning capacity	1
Learning efficiency	1
Lines of code	1
McCabe's cyclomatic complexity	1
Monetary cost	1
Number of ancilla inputs	1
Number of constant inputs	1
Number of garbage outputs	1
Number of qubits	1
Number of steps	1
Optimal	1
Privacy	1
Probability of success	1
Q-UML	1
Regular lattice	1
Results	1
Reversibility	1
Runtime	1
Searching performance	1
Secure	1
Speed	1
Success probability	1
Time complexity	1
Time cost	1
Training time	1

Understandability	1
Uniformity	1
Unitary	1
Unsharp quantum measurement	1
Width	1
Query complexity	1
Number of non-local gates	1

Table 12: Responses for RQ3 categorized as complexity/size, cost/resources, error/success, performance/efficiency, precision/quality, techniques or security.

Complexity or size related parameters			
Number of gates	Depth	Architectural design size	Asymptotic complexity
McCabe's cyclomatic complexity	Complexity	Composability	Computational complexity
Number of garbage outputs	Lines of code	Circuit size	Number of ancilla inputs
Number of constant inputs	Detailed design size	Number of qubits	Number of steps
Number of non-local gates	Width	Query complexity	Time complexity
Cost or resource related parameters			
Cost effective	Cost of failure	Iteration cost	Monetary cost
Quantum cost		Time cost	
Error or success related parameters			
Fault-tolerance	Failure probability	Error probability	Error rate
Success probability			
Performance or efficiency related parameters			
Performance	Speedup	Iteration speed	Time efficiency
Computational speed	Fast	Learning capacity	Learning efficiency
Regular lattice	Runtime	Searching performance	Speed
Training time			
Techniques related to evaluation			
Algorithmic quantum cooling		Unsharp quantum measurement	
Bug evaluation		Q-UML	
Security related parameters			
Privacy		Secure	

Table 13: Verification or validation of quantum software and the number of times each one of them appeared (counts) in the 11 primary studies for RQ4.

Quantum verification or validation	Counts
Error correction algorithms/codes	8
Quantum debugging	3
Readout-error protocols & mitigation	2
Run the program multiple times and observe its probable result (check correctness)	2
White-box testing	2
Compilation and Hardware-dependent optimization	1
Quantum provenance	1
Fidelity of the gates	1
Cost function optimization	1
Use of benchmarks	1
Sampling of pseudo-random quantum circuits	1
Unfolding techniques (readout-error mitigation)	1
Store the error model in the form of a correction matrix and apply this matrix to the results obtained	1
Induction and algebraic reasoning	1

Unsharp quantum measurement	1
Black box testing for quantum computers	1
Chernoff bound	1
Code review	1
Birkhoff-von Neumann quantum logic in reasoning about quantum programs	1
Hoare-like logic	1
Model-checker for verifying properties of the quantum systems	1
Algorithm for model-checking quantum systems described as super-operator valued Markov chains	1
Functional testing	1
Fuzz testing	1

Table 14: Responses for RQ4 categorized as error correction & mitigation, formal verification & modeling, measurements & limits, program verification & debugging, reasoning & logic, and testing.

Error correction & mitigation		
Error correction algorithms/codes	Readout-error protocols & mitigation	Fidelity of the gates
Store the error model in the form of a correction matrix and apply this matrix to the results obtained		
Formal verification & modeling		
Quantum provenance	Model-checker for verifying properties of the quantum systems	
Algorithm for model-checking quantum systems described as super-operator valued Markov chains		
Measurements & limits		
Unsharp quantum measurement	Chernoff bound	
Program verification & debugging		
Run the program multiple times and observe its probable result	Quantum debugging	
Compilation and Hardware-dependent optimization	Cost function optimization	
Reasoning & logic		
Induction and algebraic reasoning	Hoare-like logic	
Birkhoff-von Neumann quantum logic in reasoning about quantum programs		
Testing		
Black box testing for quantum computers	Use of benchmarks	Code review
Sampling of pseudo-random quantum circuits	Functional testing	Unfolding techniques
White-box testing for quantum simulators	Fuzz testing	

Table 15: Limitations of quantum software and the number of times each one of them appeared (counts) in the 17 primary studies for RQ5.

Quantum software limitations	Counts
Number of qubits	6
Limited size	6
Characteristics of the hardware	4
Coherence/Decoherence time	3
Depth of the circuit	3
Cost	2
Number of gates	2
Quantum mechanic constraints	2
Qubit connections constrains	2
Time	2
Error	2
Fidelity of quantum gates	2
Intrusiveness of measurement	2
Noise	2
Limitations of the gates	2
Computational limitations	1

Connection between different quantum platforms	1
Entry barriers	1
Error correction implies a high overhead	1
Framework issues	1
Lack of knowledge for bug-free code	1
Lack of knowledge of testers to write adequacy test cases	1
Lack of knowledge on which language features result in incorrect code	1
Layout synthesis	1
Limitations imposed by quantum physics interactions and properties	1
Limitations imposed by unitary and reversibility requirements	1
Limitations of public accounts	1
Limitations of quantum computers	1
Limitations of quantum modular computations (given any inputs, they generate the same outputs)	1
Quality	1
Quantum data collection	1
The algorithms are difficult to understand, reuse and extend to classical programmers	1
Limitation on the complexity of the implementations	1
Inability to observe the inner working of a program	1
Classical logic does not always have an appropriate quantum counterpart	1
Impossibility of predicting the properties of a particle	1
Most methods for implementing quantum computing are restricted to literature or software implementation	1

Table 16: Responses for RQ5 categorized as hardware, interoperability, operational, performance, software, and testing & development limitations.

Hardware limitations			
Number of qubits	Limited size	Characteristics of the hardware	Computational limitations
Qubit connections constrained by device layouts		Quantum mechanic constraints	Depth of the circuit
Interoperability limitations			
Connection between different quantum platforms			
Limitations imposed by unitary and reversibility requirements			
Limitations imposed by quantum physics interactions and properties			Intrusiveness of measurement
Operational limitations			
Cost	Entry barriers	Limitations of quantum computers	Quantum data collection
Performance limitations			
Time	Coherence/Decoherence time	Noise	Number of gates
Quality		Fidelity of quantum gates	
Software limitations			
Framework issues	Layout synthesis	Limitations of public accounts	
Limitations of quantum modular computations		Inability to observe the inner working of a program	
Classical logic does not always have an appropriate quantum counterpart			
Most methods for implementing quantum computing are restricted to literature or software implementation			
Testing & debugging			
Error	Lack of knowledge on which language features result in incorrect code		
Lack of knowledge for bug-free code		Lack of knowledge of testers to write adequacy test cases	
Error correction implies a high overhead		Limitation on the complexity of the implementations	
The algorithms are difficult to understand, reuse and extend to classical programmers			
Impossibility of predicting the properties of a particle			

Table 17: Quantum software challenges and the number of times each one of them appeared (counts) in the 19 primary studies for RQ6.

Quantum software challenges	**Counts**
Testing, debugging and/or maintenance	9
Complexity	4
A new approach for programming on quantum computers has to be built	3
Development of hybrid quantum programs	3
Difficult circuit design	3
Quantum algorithms are designed in a probabilistic way to solve the problems	2
The verification is complex (correctness, security)	2
Discovery of new algorithms	2
No direct equivalence between quantum and classical computing	2
Noise reduction	2
Design requires significant amounts of expert knowledge	2
A hasty initialization can cause some problems for subsequent programs	1
Absence of error-free hardware to execute quantum programs	1
Competing companies developing overlapping products	1
Computational advantage	1
Design and architectural patterns for quantum programs	1
Development of compilers for quantum programming languages	1
High number or ancilla inputs and garbage outputs	1
Interactive debugging (white-box)	1
Layout synthesis	1
Limited number of qubits and gates (it may not be enough to encode data)	1
Loading classical data	1
Low-level programming	1
Not releasing all qubits can be problematic	1
Old computational laws are not valid for quantum computing	1
Open-source quantum projects are hard to find	1
Platform-agnostic development is not a reality	1
Quality management	1
Quantum programming language definition	1
Quantum software has to be economical, reliable and efficient	1
Qubit mapping in NISQs	1
Security and privacy	1
Selection of suitable hardware	1

Table 18: Responses for RQ6 categorized as hardware, interoperability, operational, performance, software, and testing & development challenges.

<table>
<tr><th colspan="3">Hardware challenges</th></tr>
<tr><td>Absence of error-free hardware to execute quantum programs</td><td colspan="2">Not releasing all qubits can be problematic</td></tr>
<tr><td>Classical simulation of quantum computing</td><td>Noise</td><td>Qubit mapping in NISQs</td></tr>
<tr><td>Limited number of qubits and gates</td><td colspan="2">Availability of the technology</td></tr>
<tr><th colspan="3">Interoperability challenges</th></tr>
<tr><td>Platform-agnostic development is not a reality</td><td colspan="2">Selection of suitable hardware</td></tr>
<tr><td colspan="3">Competing companies developing overlapping products</td></tr>
<tr><th colspan="3">Operational challenges</th></tr>
<tr><td colspan="2">A hasty initialization can cause some problems for subsequent programs</td><td>Reliable measurements</td></tr>
<tr><td>Some algorithms cannot be executed in the near term</td><td>Inability to know when to observe</td><td>Loading classical data</td></tr>
<tr><td colspan="3">Finding an accurate solution with low computational cost</td></tr>
<tr><th colspan="3">Performance challenges</th></tr>
<tr><td>The error-per-gate is independent of the system size</td><td colspan="2">High number or ancilla inputs and garbage outputs</td></tr>
</table>

The need for more complex gates	Computational advantage	Complexity
Software challenges		
Quantum programming language definition	Low-level programming	Discovery of new algorithms
Layout synthesis	Development of hybrid quantum programs	
Open-source quantum projects are hard to find	Quantum software has to be economical, reliable and efficient	
Design and architectural patterns for quantum programs	No direct equivalence between quantum and classical computing	
Upgrade of security features to quantum	Old computational laws are not valid for quantum computing	
A new approach for programming on quantum computers has to be build		
There is a small finite universal set of quantum circuits that are implementable		
Design requires significant amounts of expert knowledge	Development of compilers for quantum programming languages	
Testing & Development challenges		
Quality management	Testing, debugging and/or maintenance	Security and privacy
The verification is complex	Interactive debugging	Difficult circuit design
Quantum algorithms are designed in a probabilistic way to solve the problems		Design error correction solutions