European Journal of Risk Regulation (2023), 14, 435–456
doi:10.1017/err.2023.71

SYMPOSIUM ON CLIMATE, AI & QUANTUM

Introducing a Research Programme for Quantum Humanities: Theoretical Implications

Astrid Bötticher[1,2], Jose Hernandez[3], Matthias C. Kettemann[2], Volker Gast[1] and Rodrigo Araiza Bravo[4]

[1]Friedrich Schiller University Jena, Jena, Thuringia, Germany, [2]Leopold-Franzens-Universität Innsbruck, Innsbruck, Austria, [3]Florida State University Research Computing Center, Tallahassee, FL, USA and [4]Harvard University, Cambridge, MA, USA

Corresponding author: Astrid Bötticher; Email: astrid.boetticher@uni-jena.de

Abstract

Quantum computing is a form of computing based on the principles of quantum mechanics. Quantum computing promises to revolutionise society through technological solutions to previously unsolvable problems or by enhancing the capacities of current computational technologies. Additionally, quantum computing has the potential to revolutionise the humanities and social sciences. We denote the study of these changes as "quantum humanities", whose study focuses on the potential of quantum computing. This paper proposes a research programme for quantum humanities, which includes the application of quantum algorithms to humanities research, reflection on the methods and techniques of quantum computing and evaluation of its potential societal implications. Moreover, we argue that, foundationally, quantum mechanics has serious implications for the ways in which data and information are used to produce seemingly objective technologies. Thus, quantum computing is a nexus for the study of knowledge itself. This research programme aims to define the field of quantum humanities and to establish it as a meaningful part of the humanities and social sciences.

Keywords: Quantum humanities; responsible research and innovation (RRI); transformation assessment

I. Introduction

From the cradle to the grave, modern human life is surrounded by technology, shaped by technology and dependent on technology. Our lives are defined by the constant encounter, use, production, conception, design and interpretation of technology. The omnipresence of technology in our lives is perhaps especially true in the case of computing technologies.[1] From time to space, our living conditions are largely technically constructed.[2] To put it as clearly as possible: one important aspect of the "human condition" is technology and its development.[3]

[1] M Weiser, "The Computer of the 21st Century" (1991) 3 Scientific American 265; H Reimer, "BSI Studie: 'Pervasive Computing: Entwicklungen und Auswirkungen'" (2006) 30 Datenschutz und Datensicherheit 748.

[2] M Castells, *The Rise of the Network Society*, 2nd edition (Oxford, John Wiley & Sons 2010).

[3] H Arendt, *The Human Condition* (Chicago, IL, University of Chicago Press 1958.

As Jasanoff explains, the recent rise of technologies has co-produced new definitions of what constitutes humanity and autonomy.[4] As Rammert recently put it, technology and culture are interwoven.[5] Technology is part of everyday life, meaning: "Techniques are without question mediating, shaping, and founding elements of social actions and social systems in all times and places. [...] Thus, techniques are not only engineering constructions of effective tools and machines, but also social constructions of the means and forms of working, researching, communicating, and living in societies."[6] As a result, computational technologies are constantly given agency to choose what we should buy,[7] who should be labelled as criminals[8] and what it means to win a democratic election.[9] Rammert states that technical infrastructure consists not only of the individual pieces of apparatus and networks, but also of authoritative social standards (eg those produced via the architecture of an apparatus such as the architecture of software), economic systems, legal structures and regulatory authorities such as operator organisations.[10] Because this is so, we cannot think of technologies as technical artefacts to be considered in isolation. Instead, we must consider the overall social context and impacts of the technical artefact, which in our case is the quantum computer.

Quantum computers, and quantum technologies in general, have become an increasingly important part of our world, as some experts claim.[11] The impact that this new form of computing has had and will have on our society and especially in the fields of the humanities is still a matter of debate. To assess these possible changes, preliminary works coined the term "quantum humanities", in analogy to the "digital humanities".[12] A consequent analysis of the initial understanding of this new domain has shown that a conceptual extension is fruitful here: the term "quantum humanities" refers, on the one hand, to the use of quantum algorithms in the humanities, allowing modified or even new questions in the humanities and social sciences to be addressed. On the other hand, it must also include the evaluation of the possibility of the deep and widespread impacts on society that this fundamentally new technology – quantum computing – is expected to have by some experts, the details of which remain in question.[13] Therefore, we can state that this emerging field is composed of the following elements: (1) the *application* of quantum algorithms within a wide variety of research questions raised in the humanities

[4] S Jasanoff, *Reframing Rights: Bioconstitutionalism in the Genetic Age* (Cambridge, MA, MIT Press 2011. See also: S Jasanoff and S-H Kim, "Containing the atom: Sociotechnical imaginaries and nuclear power in the United States and South Korea" (2009) 47(2) Minerva 119.

[5] W Rammert, "The Cultural Shaping of Technologies and the Politics of Technodiversity" in KH Sørensen and R Williams (eds), *Shaping Technology, Guiding Policy – Concepts, Spaces & Tools* (Cheltenham, Edward Elgar Publishing 2002).

[6] W Rammert, "Technik, Handeln und Sozialstruktur: Eine Einführung in die Soziologie der Technik" (2006), Technical University Technology Studies Working Papers TUTS-WP-3-2006, 8 <https://nbn-resolving.org/urn:nbn:de:0168-ssoar-11997> (last accessed 19 September 2023).

[7] DE Bambauer and M Risch, "Worse Than Human?" (2021) 53 Arizona State Law Journal 1091.

[8] A Najibi, "Racial Discrimination in Face Recognition Technology" (Science in the News, Harvard University, 2020) <https://sitn.hms.harvard.edu/flash/2020/racial-discrimination-in-face-recognition-technology/> (last accessed 21 September 2023).

[9] J Carson, "Opening the Democracy Box" (2001) 31(3) Social Studies of Science 425ff.

[10] W Rammert, *Technik – Handeln – Wissen Zu einer pragmatistischen Technik- und Sozialtheorie*, 2nd edition (Berlin, Springer 2016) p 7.

[11] D Touzalin et al, "Quantum manifesto – A new era of technology" (Quantum Manifesto for Quantum Technologies | FUTURIUM | European Commission 2016) <https://ec.europa.eu/futurium/en/content/quantum-manifesto-quantum-technologies.html> (last accessed 21 Septmeber 2023).

[12] J Barzen and F Leymann, *Quantum Humanities – A Vision for Quantum Computing in Digital Humanities* (Berlin, Springer 2019) pp 2–3.

[13] JF Bobier et al, "What Happens When 'If' Turns to 'When' in Quantum Computing?" (Boston Consulting Group Publisher, 2021) <bcg-what-happens-when-if-turns-to-when-in-quantum-computing-jul-2021-r.pdf> (last accessed 21 September 2023).

and social sciences; (2) *reflection* on the methods, techniques and impacts that are connected to quantum computing and its philosophical foundations; and (3) the societal, cultural and social (including behavioural) *implications* that are expected to have the potential for disruption by some experts,[14] although others call this "hype".[15]

This article aims to contribute to addressing the following questions: how can quantum humanities be defined? What kind of research programme emerges from the field? What innovations do quantum humanities offer? And how can they be meaningfully embedded in the humanities? Our contribution is an elaboration of these core themes, ensuring a comprehensive mapping of the subject matter in order to lay the foundations of the research programme and allow for critical engagement with and in the field. This serves as preliminary work for assigning quantum humanities a meaningful role within the humanities.

In this work, we mainly limit our argument and the proposal for the programme of quantum humanities to the confines of quantum computing. We make this choice due to the existing changes that quantum computing has already caused in other fields of knowledge and the framing of previous definitions. The arguments we develop in this work can be extended to cover other fields of quantum technologies due to their common basis, even if their specific impacts or societal implications are different.[16]

1. Development of quantum technologies

To be able to understand the possible impact of quantum technologies on the humanities, we must first understand their history. The first quantum revolution was triggered by the realisation that electrons, typically thought of as particles, can behave like waves. Similarly, light, which was previously conceived of as a wave phenomenon, can behave like

[14] J Kietzmann et al, "Hello Quantum! How Quantum Computing Will Change the World" (2021) 23(4) IT Professional 106ff. See also: P Cooper et al, "Quantum Computing Just Might Save the Planet" (*McKinsey Digital*, 19 May 2022) <https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/quantum-computing-just-might-save-the-planet> (last accessed 21 September 2023). See also: C Meier, "In the next 20 years, the quantum computer will become a reality" (Interview, *Helmholtz Newsroom*, 2020) <https://www.helmholtz.de/en/newsroom/article/in-the-next-20-years-the-quantum-computer-will-become-a-reality/> (last accessed 21 September 2023).

[15] SD Sarma, "Quantum Computing Has a Hype Problem" (*MIT Technology Review*, 28 March 2022) <https://www.technologyreview.com/2022/03/28/1048355/quantum-computing-has-a-hype-problem/> (last accessed 21 September 2023). See also: J Horgan, "Will Quantum Computing Ever Live Up to Its Hype?" (*Scientific American*, 20 April 2021) <https://www.scientificamerican.com/article/will-quantum-computing-ever-live-up-to-its-hype/> (last accessed 21 September 2023).

[16] There are specific aspects that might be unique to each area of quantum technology. However, many of the fundamental issues and challenges associated with quantum technologies are similar enough that insights from other fields can be used and applied to quantum metrology, quantum sensing and quantum communication. Quantum metrology, sensing and communication are all based on the principles of quantum mechanics and use quantum mechanical phenomena to solve secured communication tasks. Since quantum computers are also based on these quantum mechanical principles, there is a common basis. Here, we find a similarity to digital humanities, where all digital devices and technologies from web development to data analysis are dealt with in digital humanities. Similarly to digital humanities, the differences in the various quantum technologies are in the implications, applications, reflections and developments – not in the framework. Future papers will have to deal with other applications. The interactions and synergies between the different subfields of quantum technology could be intensified and lead to innovative solutions (ie studies focusing on other quantum technologies than quantum computing could be developed according to the research outline we develop here). Acceptance and regulation of new technologies often depend on similar factors, whether they are quantum computers or quantum technologies such as quantum metrology, quantum sensing or quantum communication, which is important for development, applications and implications of the technologies as a whole. The results based on one of these innovations could help to better understand quantum technologies as a whole. It makes sense to create a common framework for research, as other research and working groups are also working on these issues in parallel. See, eg, O van Deventer et al, "Towards European standards for quantum technologies" (2022) 9 EPJ Quantum Technology 33.

particles. These discoveries led to the formulation of quantum mechanics. Quantum mechanics enabled a better theoretical understanding of nature as being made up of elementary fields, of which particles are specific vibrational modes. These theoretical underpinnings amounted to explaining experiments such as radiation, crystallographic structures, conductivity and novel technologies such as magnetic resonance imaging (MRI). The first quantum revolution made it possible to describe and explain particles and their behaviour, so that one could deal with the given capabilities of the natural particles of the periodic table and use them to develop technologies such as MRI, lasers and more. The second quantum revolution was brought about by the realisation that quantum mechanical objects contain and process information in ways that just particles or just waves cannot. This realisation has fuelled research into controlling simple objects such as atoms and complex systems such as composite particles, quantum dots, excitons, plasmons and more. The computing technology envisioned from controlling information in these systems is usually called "quantum technology". Research into quantum technologies, as summarised by Dowling and Milburn, seeks to develop useful engineering tools that exploit the principles of quantum physics that possess no classical counterparts, such as interference, superposition and entanglement.[17] In the literature, quantum technologies are often divided into four areas: quantum metrology, quantum simulation, quantum communications and quantum computing.[18]

Even though they are in their infancy, today's quantum computers have played a contributing role in our world, and experts claim that they are meaningful and will become even more impactful as their development continues.[19] The highly anticipated form of fault-tolerant quantum computers is not fully realised today, so we are in the age of the noisy intermediate-scale quantum (NISQ): error-prone computers whose potential has not been fully exploited.[20] Quantum computers employ quantum versions of "bits", called "qubits", for computation. Different qubit approaches or architectures are already on the market: ion trap quantum computers, superconductor quantum computers, photonic circuits and, although it is debated as to whether it is a "true quantum computer", the quantum annealer.[21]

In their current iteration, quantum computers are already impacting humanities research through the application of quantum algorithms for humanities-focused and socially relevant questions.[22] Alongside this, quantum computing applications might be

---

[17] JP Dowling and G Milburn, "Quantum technology – the second quantum revolution" (2003) 361(1809) Philosophical Transactions: Mathematical, Physical and Engineering Sciences, Information, Knowledge and Technology 1655ff.

[18] A Acín et al, "The quantum technologies roadmap – a European community view" (2018) 20 New Journal of Physics 080201.

[19] JM Arrazola, E Diamanti and J Kerenidis, "Quantum superiority for verifying NP-complete problems with linear optics" (2018) 4 npj Quantum Information 56. See also: S Boixo et al, "Characterizing quantum supremacy in near-term devices" (2018) 14 Nature Physics 595–600. See also: Project website QuSCo | Publications <qusco-itn.eu> (last accessed 21 September 2023).

[20] J Preskill, "Quantum Computing in the NISQ Era and Beyond" (2018) 2 Quantum 79.

[21] J Marre, "quantencomputer-info - Ein freies Online-Buch über Quantencomputer. Welche Quantencomputer gibt es jetzt schon?" <quantencomputer-info.de> (last accessed 29 September 2023). See also: PLANQK, "Superconductor vs. ion traps: Properties of different quantum architectures" (7 December 2020) <https://planqk.de/news/superconductor-vs-ion-traps-properties-of-different-quantum-architectures/> (last accessed 21 September 2023). See also: JM Arrazola et al, "Quantum circuits with many photons on a programmable nanophotonic chip" (2021) 591 Nature 54ff. See also: NB Linke et al, "Experimental comparison of two quantum computing architectures" (2017) 114(13) Proceedings of the National Academy of Sciences of the United States of America 3305–10. Special series of Inaugural Articles by members of the National Academy of Sciences elected in 2016 (1 February 2017).

[22] J Barzen, "From Digital Humanities to Quantum Humanities: Potentials and Applications" in ER Miranda (eds), *Quantum Computing in the Arts and Humanities* (Berlin, Springer 2022). See also: JM Arrazola, "Quantum-inspired algorithms in practice" (2020) 4 Quantum 307.

stimulating transformation processes in the areas of politics, the economy and society, a statement whose truth has yet to be proven but needs to be investigated.

Quantum computing may also have an impact as a tool when it comes to humanities-motivated analysis of large datasets or complicated linkages, as in the field of social network analysis.[23] At the same time, it is expected to have an impact on our societies as path dependencies are created and networks are built while capturing the interest of the research community.[24] It has not yet been explored whether these changes will actually have an impact on human development and what this impact might be. Additionally, there is a question of whether such applications will fundamentally change the way we research and develop or lead to new insights through reflection on these technologies, which some believe will occur.[25]

Pragmatically, quantum humanities are not about fully understanding every detail of quantum mechanics and its preconditions, just as the humanities are not limited to philosophy or to ontological debate. Quantum humanities are also about epistemology and the simple yet daunting fact of introducing quantum technology and its outcomes into the respective work of a full range of disciplines subsumed under the humanities. This introduction is necessary, as innovations in quantum technologies, such as the quantum computer, are predicted to become important tools in the future for a number of applications, many of which we cannot predict today, and it is unclear whether, how, when and what will undergo any such changes.[26]

2. *Previous descriptions of quantum humanities*

Having described the development of quantum technologies and some of the early possibilities for changes, it will come as no surprise that the field of quantum humanities is still in its early stages. Therefore, its precise boundaries and methodologies are being actively explored. As an interdisciplinary field, it encourages collaboration between quantum physicists, computer scientists, philosophers, linguists, anthropologists, literary scholars, historians and other experts from both the natural sciences and the humanities. Johanna Barzen, who coined the term "quantum humanities", argued that traditional research in the humanities has relied on hermeneutics, which involves interpretation and analysis based on the texts or objects of study.[27] With the introduction of digital humanities, computational methods have been integrated to support and enhance hermeneutic approaches. However, the limitations of classical computers become apparent when considering the potential of quantum computers. Therefore, the term "quantum humanities" was proposed by Barzen to capture the unique capabilities of quantum technologies for solving humanities-related problems. With its fundamentally different approach and advantages, quantum computing is seen as a new field that extends and enriches existing methods in digital humanities.[28] Barzen was one of the first scholars from the humanities to appreciate the potential of the quantum computer, presenting a systematisation project (MUSE) demonstrating that the quantum computer is a tool to be

[23] N Amoroso et al, "Potential energy of complex networks: a quantum mechanical perspective" (2020) 10 Scientific Reports 18387.

[24] Such as the research project led by Christopher Coenen: Karlsruhe Institute of Technology (KIT): QuTec – Quantum Technology Innovations for Society. See also: the Centre for Quantum and Society under Quantum Delta in the Netherlands <https://quantumdelta.nl> (last accessed 29 September 2023).

[25] C Coenen et al, "Quantum Technologies and Society: Towards a Different Spin" (2022) 16 Nanoethics 1ff.

[26] F Gerke et al, "Quantum Awareness im Ingenieurwesen: Welche Kompetenzen werden in der Industrie von morgen gebraucht?" (2020) 1 PhyDid B - Beiträge zur DPG-Frühjahrstagung.

[27] J Barzen and F Leymann, "Quantum humanities: a vision for quantum computing in digital humanities" (2019) 35 SICS Software-Intensive Cyber-Physical Systems 2–3.

[28] ibid.

taken seriously.[29] Yet MUSE was defined as being part of digital humanities at first, and the term "quantum humanities" was developed later based on the same project, drawing on the same combination of hermeneutics and its extension through the methodological use of the quantum computer.[30]

But even though hermeneutics is an important approach in the humanities, it is not the only one, which is why quantum humanities necessitates a foundation apart from this singular approach. Why are quantum humanities not just digital humanities? Apart from the fact that a quantum computer can do things much faster, what makes this machine so special that it inaugurates its own field of research?

The field of digital humanities is constantly evolving, and definitions can quickly become outdated or restrictive.[31] Traditionally, digital humanities combine traditional humanities disciplines with computational tools and technologies, yet some explore (on a smaller scale) the impacts of digital technologies on society.[32] Quantum humanities breaks with this tradition, as it has a greater focus on development, reflection and the implications of this technology (see Section III). Yet quantum humanities are a continuation of this technology-based way of working, using quantum technology. However, because quantum physics challenges the fundamental ideological assumptions of realism and determinism, quantum humanities possess a new quality that separates them from digital humanities in addition to just increased computing power. In contrast to digital humanities, which are primarily concerned with methods of using digital technologies, quantum humanities take on a qualitative value of their own because they are based on quantum mechanics (see also Section III.3) and explore possible impacts on society to a greater extent than digital humanities.[33]

To grasp this difference, we must delve into the object itself. A quantum computer is a different machine from a universal computer as it uses quantum mechanics to perform calculations.[34] Another argument as to why quantum humanities are not simply digital humanities, as we claim, lies in the distinct computations performed on a quantum computer.[35] Two important functions change. First, the questions change because they have to be asked in a way that is adapted to the algorithm. This is not a trivial matter, because the quantum computer works with atoms, which calculate for us, and so our questions must find a physical equivalent. Second, the answers also change because

[29] MUSE | Institut für Architektur von Anwendungssystemen | Universität Stuttgart <uni-stuttgart.de> (last accessed 29 September 2023).

[30] J Barzen, *Wenn Kostüme sprechen – Musterforschung in den Digital Humanities am Beispiel vestimentärer Kommunikation im Film* (DPhilThesis, University of Cologne 2018).

[31] C Warwick, M Terras and J Nyhan, *Digital Humanities in Practice* (London, Facet Publishing 2012).

[32] F Jandis, *Digital Humanities* (Bonn, Gesellschaft für Informatik 2017). See also: A Koh, "A Letter to the Humanities: DH Will Not Save You" in D Kim and J Stommel (eds), *Disrupting Digital Humanities* (Santa Barbara, CA, Punctum Books 2018). See also: MP Eve, *The Digital Humanities and Literature Studies* (Oxford, Oxford University Press 2022) p 13ff.

[33] "You're going to see a lot of emphasis on tools. A lot of emphasis on big data analysis. A lot of emphasis on computation, and the power of computation. What aren't you going to see as much of? Emphasis on why computing, the conditions under which computing is manufactured, a cultural analysis of the ideologies of computing." Koh, supra, note 32, 40f. See also: M Terras, "*Computers and the Classics* – (S.) Schreibman, (R.) Siemens, (J.) Unsworth (Edd.) A Companion to Digital Humanities. Pp. Xxviii 611. Malden, MA, Oxford and Carlton, Victoria: Blackwell Publishing, 2008. Paper, £29.99, €42 (Cased, £105, €147). ISBN: 978-1-4051-6806-9 (978-1-4051-0321-3 Hbk)" (2009) 59(1) The Classical Review 288–90. See also: A Burdick et al, *Digital_Humanities* (Cambridge, MA, MIT Press 2012).

[34] RP Feynman, "Simulating physics with computers" (1982) 21 International Journal of Theoretical Physics 467–88.

[35] See: J Barzen, "From Digital Humanities to Quantum Humanities: Potentials and Applications" in ER Miranda, *Quantum Computing in the Arts and Humanities: An Introduction to Core Concepts, Theory and Applications* (New York, Springer International Publishing 2022).

quantum algorithms are probabilistic. As a result, patterns are recognised through constant iterations. There are things that quantum computers can do that no probabilistic quantum computer can do. An example of this is the generation of long-range entanglement, which can be proven to be infeasible to capture when using a classical quantum computer. Computation and survey strategies are changing and new approaches will be developed. This clearly has an impact that justifies the claim that quantum humanities are different from digital humanities.[36]

A research field cannot be based solely on the use of a device such as the quantum computer because this would not do justice to the humanities as a whole. This new generation of technologies *might lead* to new machines, new processes, new cultures, new activities, new knowledge and new institutions. It is a wave of disruptive innovation in the deep-technology sector, and it is our responsibility to test this statement and make scientifically guided observations about this course of development and its possible significance. Today, we can see that the first steps of *development* can follow the conditions of *development* and emergence, we can describe the first innovations and their significance for *applications* or their *implications* on society and we can *reflect* on what this new knowledge means.

II. Defining quantum humanities

To describe quantum humanities and arrive at a research programme, we want to be clear on what fields we are including in the term "humanities". The humanities typically include history, philosophy, religious studies, modern and ancient languages, literature, the visual and performing arts, media and cultural studies, archaeology, anthropology, pedagogy, human geography and law, and some add the much more recent political sciences that emerged from public law. The extent to which questions in the humanities are also affected by the development of quantum computing is shown, for example, by questions about democracy in technology, as discussed by Seskir et al.[37]

Quantum humanities represent a research paradigm that is interdisciplinary. As described, the use of quantum computers changes our working modes, and so we can develop new *applications* within the humanities. Therefore, new applications need to be part of a research framework. If we consider the *implications* of quantum technology in terms of the fundamental questions of the humanities (ie the ethical, the legal, the societal, the cultural, the political and everyday consequences), this provides a second step in a framework for an emerging research programme. In the humanities, the interpretation of technology *development* in literary, artistic, gender and cultural contexts and its critical *reflection* are important, but also in relation to different periods, power relations or cultural traditions. The analysis of societal dynamics and structures in relation to technology, the study of technology acceptance, social networks or technology-induced changes in institutions, new ways of producing knowledge and exploring the foundations of knowledge itself are potential fields of interest.

For these reasons, we suggest the following definition of quantum humanities:

> Quantum humanities represent a research programme based on the development of the second quantum wave that encompasses theories, concepts and reflections that may be based on quantum mechanics but whose research focus is on the

[36] R De Wolf, "The potential impact of quantum computers on society" (2017) 19(4) Ethics and Information Technology 271–76.

[37] ZC Seskir et al, "Democratization of quantum technologies" (2023) 8 Quantum Science and Technology 2. See also: R Owen, P Macnaghten and J Stilgoe, "Responsible research and innovation – from science in society to science for society, with society" (2012) 39 Science and Public Policy 751–60.

developments related to the second quantum wave and the society that emerges with it. Therefore, quantum humanities includes those humanities researchers who utilise quantum technology among their methodological instruments or reflect on their usage, as well as those who examine the socio-cultural implications related to devices of the second quantum wave or their development.

1. Four areas of research

Research within quantum humanities is held together by a bracket that asks "how things are done differently" and subsequently "how things are viewed differently" as well as "how these activities are institutionally arranged differently"[38] while looking at day-to-day scientific practice (and "patterns of [other] practices"), institutional "regimes and styles" such as the organisation of new institutional structures, routine selection or the development of rules, as well as the "configurations of valued signs and symbols" regarding the second wave of quantum innovation.[39] In the short term, and especially given the new emergence of technology in its early developmental stages, quantum humanities also has an important role to play in examining the choices that could set a course for later developments.[40] Therefore, to be able to analyse these choices and their consequences we must look at technology as a process following the Greek concept of "*techne*" – doing something – that describes action as a matter, subdivided into three areas: "Firstly, the using handling of the technical objectivations (work, consumption, use, and utilisation), – secondly, the generating handling (production, construction, invention, discovery) and – third, the activities of the technical object itself (operation, mechanical processes, automatisms)."[41]

We will take up the process orientation, which lies in the ancient Greek concept, to classify our four areas of research. As we go forward, "quantum humanities" will refer to the following four distinct areas (Fig. 1): (1) the *application* of quantum algorithms in the humanities or in sciences that bring about knowledge that will (2) allow the humanities to *reflect* on its use at a theoretical and methodological level, which will also include (3) the evaluation of the societal, cultural and social *implications* and (4) give insights into the *development* of research, education or national innovation systems for quantum computers.[42]

[38] Please note that we follow here a general interpretation of the institution as developed by Emile Durkheim that later has been used and further developed by DC North.

[39] Rammert, supra, note 5, 175.

[40] The discussion about the connection between design and culture sees a large list of theoretical interventions. See the design for values approach here: D Collingridge, *The Social Control of Technology* (London, Frances Pinter 1980). See also: J Hoven et al (eds), *Handbook of Ethics, Values, and Technological Design* (Berlin, Springer 2015). See also: B Friedman et al, "Value sensitive design and information systems" in P Zhang and D Galletta (eds), *Human-Computer Interaction in Management Information Systems: Foundations* (Armonk, NY, M.E. Sharpe 2006) pp 348–72. This has also entered other fields of study such as political geography, where the discussion about the design of systems has been connected to political power.

[41] W Rammert, "The Technical Construction as Part of the Social Construction of Reality". Conference paper presented at *New Perspectives in the Sociology of Knowledge: On the Actuality of a Research Paradigm. Thomas Luckmann on his 75th Birthday* (Konstanz, 21 June 2002). Technical University Berlin, Technology Studies Working Papers TUTS-WP-2-2002, 8.

[42] Please see the discussion: W Rammert, "Wie die Soziologie zur 'künstlichen Intelligenz' kam; eine kurze Geschichte ihrer Beziehung" in F Muhle (ed.), *Soziale Robotik: Eine sozialwissenschaftliche Einführung* (Berlin, De Gruyter 2023). Please see also: A Bötticher et al, "Reframing Political Power in the Digital Constellation - Taking Technopolitics Seriously". Future Law Working Paper 2, 2023. Future Law Working Papers – Universität Innsbruck <uibk.ac.at> (last accessed 29 September 2023).

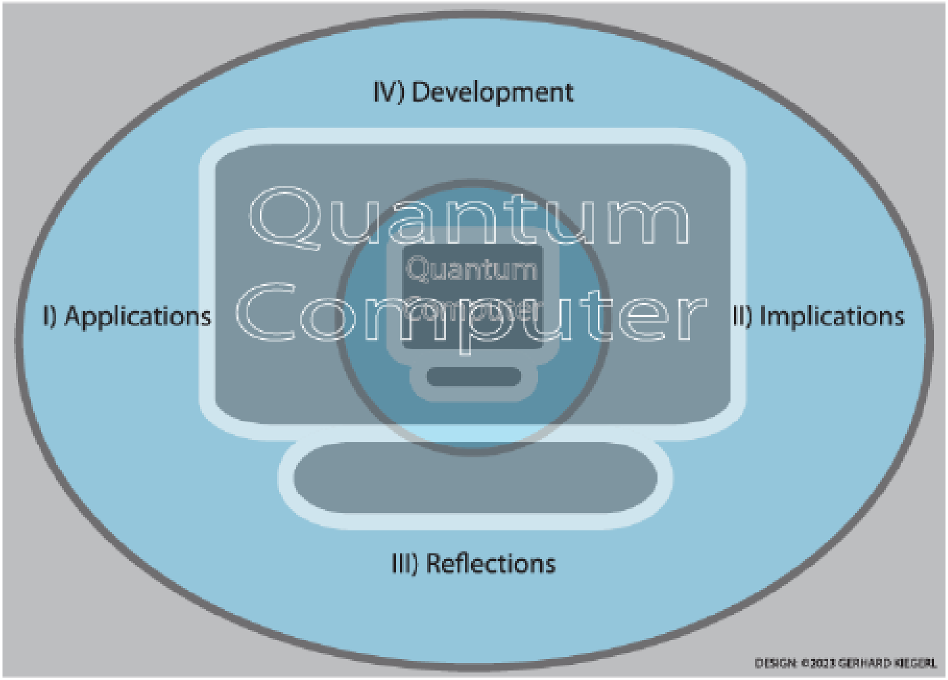

Figure 1. Core elements of quantum humanities.
Source: Astrid Böttcher. *Design:* Gerhard Kiegerl.

III. Contents of the areas of research

By presenting a research body, we follow the call of Pieter E. Vermaas to normalise quantum technology.[43] Due to the breadth of disciplines and topics we are grouping under the umbrella of "quantum humanities", it is critical to be clear on what is included under each area of research and its consequences for the field.

1. Applications

The most straightforward of all of our subfields to define is the applications – or the use of quantum computing to explore humanities questions and produce works in the humanities. In this subfield we consider the following questions: what kind of visions for applications can we develop for the humanities? How can we use quantum computing to sustainably enable research in the humanities? What applications do exist and how are they affected by other sciences?

Utilising these questions as a starting point, we can already report on first experiences in the use of quantum computing for humanities-orientated research questions. Many researchers have already started experimenting and even producing work in a quantum-native manner in the humanities. Four particular fields – music, visual arts, language processing and machine learning – have already positioned their research at the vanguard of this subfield, taking advantage of the intersection of quantum technologies and the production of humanities-orientated research and artistic works. The discussion of the

[43] PE Vermaas, "The societal impact of the emerging quantum technologies: a renewed urgency to make quantum theory understandable" (2017) 19 Ethics and Information Technology 241–46.

applications here is not meant to be exhaustive but just to give a cursory view of the ways in which quantum computing is being used in humanities-related studies.

One of the application fields with an increasing number of international conferences and works is that of quantum music. Quantum music has different iterations, but most try to use quantum phenomena to explore superposition and other concepts within musical theory. Several works in this area are easily identifiable, such as Putz and Svozil, who quantised a piano.[44] When a classical music audience hears the quantum musical state, individual listeners may perceive the sound very differently. That is, they will hear only one of the different tones played by the quantised piano. To be clear, truly quantum mechanical music will never produce a unified listening experience – it is quite possible for one part of the audience to hear different manifestations of the quantum musical composition consisting of different sequences of tones, offering possibilities for aleatoricism in music.

In addition, the visual arts are exploring the quantum field. Even though quantum humanities have only just begun defining themselves over the last four years, quantum-inspired or quantum-based art has been represented in art galleries since the 2010s. Examples can be seen by the project by Heller, Swist and Thomas,[45] which utilised quantum phenomena graphically to model key works of art and expression. Others in this field have embarked on far-reaching projects such Quantum Cinema (2010–2013), which continues to be expanded on by current scientists to explore the capabilities of illustrating quantum phenomena and focusing on the visualisation of three-dimensional animated geometry.[46]

Quantum computation presents a new opportunity for those engaged in natural language processing and machine learning. In the case of natural language processing, projects are underway such as that of Coecke et al, who have designed ways to “speak” in question-and-answering formats in a quantum-native manner with existing quantum computers.[47] In the case of machine learning, projects such as MUSE (mentioned previously) have already shown the utility of incorporating quantum machine learning while also setting a precedent for when quantum computers surpass the NISQ phase and their machine learning capabilities surpass those of our more error-prone digital systems. It is important to note here that learning materials and industry requirements have already started pushing for the use of quantum approaches to machine learning due to the current state of the artificial intelligence (AI) and deep learning fields, which may lead to even more combined applications.

In addition to just strictly humanities work, quantum computing has started affecting theoretical and practical concerns in the field of law, as argued by Atik and Jeutner. For example, the phenomenon of superposition in quantum computing makes it possible to model situations in which certain behaviours are both legal and illegal. This could be helpful in resolving normative conflicts in which different legal norms overlap. Quantum computing could also improve the modelling of legal phenomena such as rule-exception dynamics and fuzzy legal categorisations. Specific application areas for quantum computing in law include optimising legal decision-making processes, reducing the burden of proof and improving machine learning in the legal context. The authors argue that two conceptual steps are necessary to explore the legal applicability of quantum

[44] V Putz and K Svozil, “Quantum music” (2017) 21 Soft Computing 1467–71.

[45] R Crease, “Quantum-Inspired Art” (*Physics World*, 2015) <https://physicsworld.com/a/quantum-inspired-art/> (last accessed 29 September 2023).

[46] RCZ Quehenberger, “Quantum Cinema and Quantum Computing” in ER Miranda (ed.), *Quantum Computing in the Arts and Humanities* (Berlin, Springer 2022).

[47] B Coecke et al, “How to Make Qubits Speak” in ER Miranda (ed.), *Quantum Computing in the Arts and Humanities* (Berlin, Springer 2022).

computing. First, the problem areas in which quantum computing enjoys "quantum dominance" need to be identified. Second, these identified areas need to be considered in a legal context. However, they emphasise that the legal significance of quantum computing will be limited to a specific subset of legal issues, and that many issues cannot be adequately addressed by (quantum) computational law.[48]

In this brief overview, we can observe that the applications of quantum computing are steadily developing those fields in the humanities, and this development has been ongoing for at least a decade in some areas, setting the foundations for more pervasive transformations among humanities applications in the coming years. In addition, by joining them together under the umbrella subfield of "applications within quantum humanities", future academics will be able to draw on the experiences and explorations of their colleagues to define and develop said field without remaining in their topic-based bubble. This joining also presents an opportunity for humanities researchers to become more informed regarding the impacts of providing their information in a quantum-native manner, increasing their interactions with the other areas of the quantum humanities here specified.

2. *Implications*

The identification of societal implications is an important goal of knowledge because achieving this enables us to advise on the transformational issues that the world is facing. According to Rammert,[49] technology is a natural part of our social structure – because, without it, entire branches of society could not be understood at all. Technologies formed industries and economic sectors, as well as technical infrastructure systems, which together formed the technostructure of society, as Mayntz explains.[50]

Quantum humanities have their practical focus on social ordering. Kornwachs and Stephan[51] explain that every device has an organisational shell. This consists of an action system and a factual system. Therefore, technology acts as a kind of transmitter for people and for society at the macro-, meso- and micro-levels. Quantum technology in general is negotiated in multiple arenas of our societies, and it might provoke new markets, new jobs, new work, new institutions, new art, new philosophies, institutional change, new kinds of policy and regulation and transformational changes within the culture.[52] Managing complexity points to the fact that we are on the verge of reconciling these various perspectives as a larger whole because the individual institutions, facilities, habits and day-to-day practices are akin to (sometimes mismatched) gears that mesh together.[53] The focus is on the pitfalls of transformation and the benefits of advancement and transitional activities in society, testifying to the transformative power of quantum computing or providing evidence to the contrary. Pitfalls include, for instance, insufficient regulation,[54] a lack of international coordination regimes,[55] insufficient democratisation in science,

---

[48] J Atik and V Jeutner "Quantum computing and computational law" (2021) 13(2) Law, Innovation and Technology 302–24.

[49] Rammert, supra, note 10, 4f.

[50] R Mayntz, "Große Technische Systeme und ihre gesellschaftstheoretische Bedeutung" (1993) 45(1) Kölner Zeitschrift für Soziologie und Sozialpsychologie 97–108.

[51] K Kornwachs and PF Stephan, "Das Mensch-Ding Verhältnis" in O Herzog and T Schildhauer (eds), *Intelligente Objekte – Technische Gestaltung, Wirtschaftliche Verwertung, Gesellschaftliche Wirkung, acatech diskutiert* (Berlin, Springer 2009) p 18.

[52] Following the interpretation of culture from Clifford Geertz as a special "frame with which things are seen differently, things are done differently, activities and institutions are arranged differently", as used by Rammert, supra, note 5. C Geertz, *Dichte Beschreibung* (Berlin, Suhrkamp 1983).

[53] Rammert, supra, note 10.

[54] CJ Hoofnagle, *Law and Policy in the Quantum Age* (Cambridge, Cambridge University Press 2021).

[55] White House, "National Security Memorandum/NSM-10" <https://www.quantum.gov/strategy/#STRATEGY-DOCUMENTS> (last accessed 21 September 2023).

reinforcing or creating a bias against women or other minorities in technology use and discourse[56] and a lack of discussion of sensible economic investments[57] and the potential use of such technology.[58] The relationship between technology and society is as multifaceted as how technology is perceived, integrated and shaped in different societal contexts. Technology has the inherent ability to exert influence and impact on various aspects of society,[59] thereby shaping and engaging the fields of the humanities. Individuals and communities perceive technologies within specific social, cultural and historical contexts as these technologies are integrated into different areas of human activity such as education, work, health, communication and leisure. Technology affects power dynamics, social inequalities, ethical considerations and the distribution of resources, and these factors influence the integration of technology into human action. By examining contextual elements such as organisational structures, legal frameworks, technological infrastructures and cultural practices, we can understand how these factors shape the adoption, use and impacts of quantum computing. The technological shell provides a framework for considering these wider implications of this technology for the humanities. Through the technological shell, we perceive the pervasiveness of the possible societal changes. This framework recognises the interconnectedness and interdependence of different aspects within the humanities.

Figure 2 presents the technological shell.[60] It provides an overview and locates the multiform processes and networks that organise these processes, be they military advantages or aspects in the fight against global warming or concrete processes and new infrastructures (eg the Quantum Internet Alliance) for fundamentally new metohds of communications based in orbit or new standards.[61]

However, the technological shell model fails to critically reflect on the parties or societal inquiries that are included and left out of the technology's design. A recent collaboration between Stanford University and the University of Oxford introduced the Quantum-ELSPI research framework, which analyses quantum technologies in the responsible research and innovation framing.[62] The ELSPI meta-paradigm focuses on predefined categories of change such as the ethical, legal, social and political implications of quantum technology. It shares some of the insights of the technological shell in that it recognises the interconnectedness and interdependence of the various dimensions.

[56] Seskir et al, supra, note 37.

[57] N Mohr et al, "McKinsey Quantum Technology Monitor" (June 2022) <https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/quantum%20computing%20funding%20remains%20strong%20but%20talent%20gap%20raises%20concern/quantum-technology-monitor.pdf> (last accessed 29 September 2023).

[58] C Ten Holter, P Inglesant and M Jirotka "Reading the road – challenges and opportunities on the path to responsible innovation in quantum computing" (2021) 35 Technology Analysis and Strategic Management 1. See also: S Chen, "Should We Build Quantum Computers At All? – A Q&A with Emma McKay, Quantum Physicist Turned Quantum Skeptic" (*APS News*, September 2022) <https://www.aps.org/publications/apsnews/202209/build-quantum.cfm> (last accessed 29 September 2023).

[59] M Koop, "Quantum ELSPI: A Novel Field of Research" (2023) <http://law.stanford.edu/wp-content/uploads/2023/05/Kop_Quantum-ELSPI_A-Novel-Field-of-Research.pdf> (last accessed 29 September 2023).

[60] In this regard, we meet with Eline de Jong, who characterises quantum technology as a "system technology". However, the chosen approach is grounded in a different rationale. See: E de Jong, "Own the Unknown: An Anticipatory Approach to Prepare Society for the Quantum Age" (2022) 1 Digital Society 15.

[61] A Bötticher, "Quantum Technology – Our Sustainable Future" [Documentary] (2021) <https://www.youtube.com/watch?v=iB2_ibvEcsE> (last accessed 17 October 2023). See also: J Dargan, "Quantum Technology: Our Sustainable Future – One Year On" (*The Quantum Insider*, 27 July 2022) <https://thequantuminsider.com/2022/07/27/quantum-technology-our-sustainable-future-one-year-on/> (last accessed 17 October 2023). See also: van Deventer et al, supra, note 16.

[62] Koop, supra, note 59;. See also: E de Jong et al, "Towards Responsible Quantum Technology. Berkman Klein Publication Series Mar 21" (2023) <https://cyber.harvard.edu/publication/2023/towards-responsible-quantum-technology> (last accessed 29 September 2023).

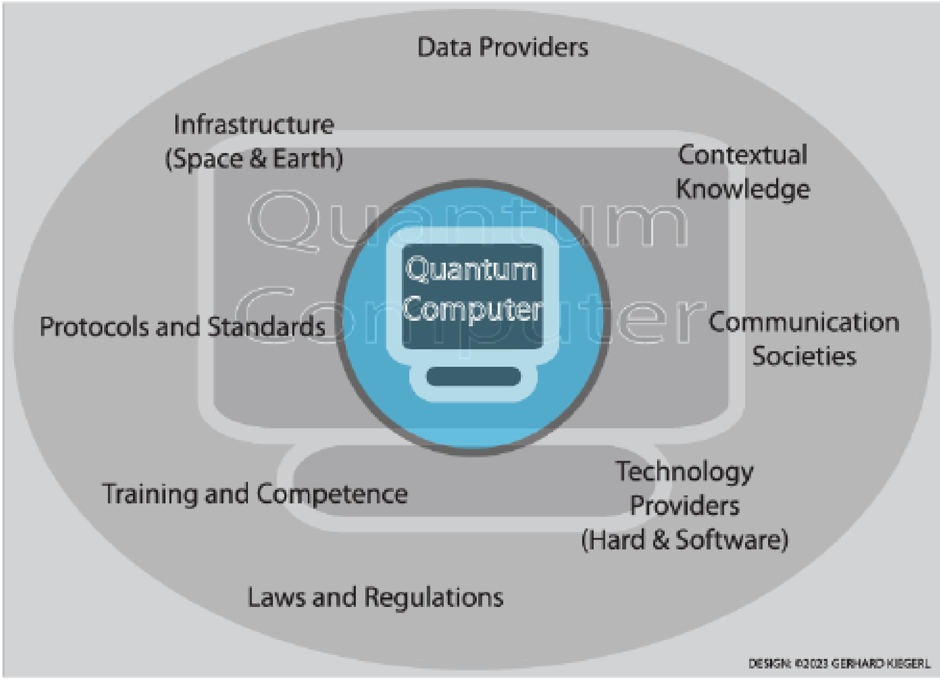

Figure 2. The technological shell, using the example of a PC.
Source: Intelligente Objekte. Acatech diskutiert. German Academy of Science and Engineering. Adapted by Astrid Bötticher.

Indeed, researchers and policymakers currently question the ethical implications of accelerating rates of discovery, the legal opportunities and challenges posed by a technology that promises to render current encryption obsolete, the limitations of building workforces upon already-stratified societies[63] and the challenges that the technology poses in the international arena.[64] Contrary to the technological shell's descriptive approach, Quantum-ELSPI insists that quantum technologies are indeed revolutionary, an assertion that justifies inquiring about the socio-political impacts of such technology.

Quantum-ELSPI reflects on several largely missing dimensions of innovation and acknowledges the interdependence between societal and technical questions. It also tacitly re-institutionalises the acceptance that there is indeed a "good" quantum-enabled global future. Quantum-ELSPI claims that such a future is deliverable through the study of or reflection on the implications of the technology while leaving unproblematised normative claims that quantum technology will revolutionise the world and benefit society. We argue that Quantum-ELSPI publicly performs a Western socio-technical imaginary – a collectively held and institutionally stabilised notion of a "good" science-enabled future.[65]

[63] See: QIST Workforce Development <quantum.gov> (last accessed 29 September 2023).

[64] In the USA, for example, quantum computing is included in claims that China is investing in emergent technologies for military and civilian incentives – what the US Department of State calls a military–civil fusion. Claims of such a fusion are used to ban the participation of Chinese scientists in the US quantum ecosystem – see Presidential Proclamation 10043 – and to ban the participation of American companies in the Chinese quantum market – see President Biden's Executive Order on this issue: <https://www.federalregister.gov/documents/2023/08/14/2023-17164/provisions-pertaining-to-us-investments-in-certain-national-security-technologies-and-products-in> (last accessed 29 September 2023).

[65] S Jasanoff and K Sang-Hyun (eds), *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power* (Chicago, IL; online edition, Chicago Scholarship Online, 21 January 2016) <https://doi-org.ezp-prod1.hul.

In democratic Western societies, knowledge orders are seen as authoritative, inevitable and seemingly factual, while societal orders are seen as subjective, changeable and legitimised through claims of objectivity. In other words, science stabilises society by the constant leveraging of expertise as a fundamental part of civic life.[66] Similarly, Quantum-ELSPI claims that quantum technologies stand to deliver societally impactful solutions. It also claims that quantum technologies can indeed change, or even improve, society systemically, and that such change can be rendered beneficial through the steering of the technology's "course". Quantum-ELSPI sees the problem of quantum innovation as to be institutionalised along the lines of responsible innovation – innovation that needs further demystification, contextualisation, stakeholder engagement, regulation and strategic positioning – reinforcing notions of "good" held by Western democracies and stakeholder capitalism. Indeed, notions of democracy in Quantum-ELSPI appear only in the sense of liberal democracies, and all other forms of governments are referred to as "authoritarian".[67] If Quantum-ELSPI is an emergent framework, it emerges from the existing social orders of Western knowledge states. It institutionalises how such a "good" quantum future is to be pursued vis-à-vis a research framework.

Quantum humanities have a different starting point of inquiry. Instead of assuming that quantum technologies will be revolutionary,[68] we assert that such claims serve to stabilise the institutionalisation of a future while obfuscating such a pursuit's uncertainty. Thus, the analysis of quantum humanities encompasses highlighting the collectives making such claims and under what authority, and the claims' historicity and materiality. Therefore, we acknowledge that social orders and quantum technological orders are co-produced.[69] That is, quantum science and technology are not merely stabilisers of a society that funds their development, but simultaneously they are efforts stabilised by social orders such as those of Western liberal democracies and technology-centric notions of democracy.[70] For quantum humanities, a "good" future need not be achieved through quantum technologies. Instead, the question of whether there exists a revolutionary or "good" quantum future, and for whom, remains to be resolved.

We argue that no quantum technology can be separated from the human, and therefore a holistic, reflexive and symmetric research programme is needed to analyse how it influences and is influenced by various societal bodies, institutions, cultural practices and human exchanges. The humanities should sit at the centre of what was previously believed to be the purely technical agenda of quantum innovation.

---

harvard.edu/10.7208/chicago/9780226276663.001.0001> (last accessed 18 August 2023). See also: C Palacios-Berraquero, L Mueck and DM Persaud, "Instead of 'supremacy' use 'quantum advantage'" (2019) 576 Nature 213. See also: I Durham, D Garisto and K Wiesner, "Physicists need to be more careful with how they name things" (*Scientific American*, 2021) <https://www.scientificamerican.com/article/physicists-need-to-be-more-careful-with-how-they-name-things/> (last accessed 29 September 2023).

[66] S Jasanoff, *Designs on Nature: Science and Democracy in Europe and the United States* (Princeton, NJ, Princeton University Press 2005).

[67] M Koop, "Quantum-ELSPI: A Novel Field of Research" (2023) 2 Digital Society 20. Page 14 states: "Given the reality of a race for technological supremacy between systemic rivals with incompatible ideologies, it is not inconceivable that the development and uptake of transnational quantum principles will run along the lines of democratic and authoritarian technology governance models. Against that background, how can we embed liberal-democratic values in globally accepted human rights sensitive interoperability standards and protocols for this cutting-edge technology, including quantum-machine learning hybrids?" This language reflects a false dichotomy between democratic and authoritarian ways of governing.

[68] de Jong, supra, note 60.

[69] S Jasanoff, "The idiom of co-production" in S Jasanoff (ed.) *States of Knowledge* (London, Routledge 2004) pp 1–12.

[70] Seskir et al, supra, note 37.

3. Reflections

Quantum computing as knowledge-making may pose important societal questions to reflect on. From an optimisation perspective, they may solve previously intractable problems concerning complex networks. From an AI perspective, they may enable significant increases in speed in language processing. From a materials perspective, they may enable breakthroughs in the design of clean energy alternatives. As a result, we might be able to ask: what can we know? How can we acquire *new or accelerated* knowledge? For whom is this knowledge important? Who is being left out of knowing? What power relations are built up and further established? And how are inequalities transformed? Therefore, quantum humanities are uniquely poised to study the methods, processes and implications of knowledge-making through quantum computers. Put differently, reflecting on quantum computing's methods, processes and implications may shed light on current uncomfortable truths, assumptions and values. Given that quantum computing is in its early stages, reflecting on these values, assumptions and pitfalls may alter the ways in which the technology is implemented and the knowledge we decide to pursue. Whether we trust a quantum computer's output – or see our research priorities as questionable due to the probabilistic nature of measurements – may tell us much about the values and assumptions that our society comes to live by[71]:

> [T]hese technologies will require the acceptance of some new concepts about the nature of reality. I am hopeful that at least some will accept these new concepts, find them appealing, and thrive with this new knowledge.[72]

Reflections on *methods* are of practical importance as this technology becomes a research tool. Digital humanities emphasise quantitative research into the research limitations and opportunities of classification, clustering and data reduction[73] and the importance of attending to the ways in which large amounts of data are obtained and processed.[74] Similarly, repositories of quantum natural language processing exemplify early equivalent problematisations.[75] Early quantum computing requires classical verification to be trustworthy. This verification demands the processing of insurmountable amounts of data, as shown in Google's experiment claiming quantum "supremacy".[76] Such processing is not scalable, resulting in quantum experts designing cultural norms for claiming trustworthy results in the presence of smaller datasets[77]

[71] An example can be found in: S Ishikawa, "Linguistic Copenhagen Interpretation of Quantum Mechanics: Quantum Language" (2019) KSTS/RR-19/003, Research Report, Department of Mathematics, Keio University, Yokohama <http://www.math.keio.ac.jp/academic/research_pdf/report/2019/19003.pdf> (last accessed 29 September 2023).

[72] DP DiVincenzo, "Scientists and citizens: getting to quantum technologies" (2017) 19 Ethics in Information Technology 247–51.

[73] M Weichbold et al, "Potential and Limits of Automated Classification of Big Data: A Case Study" (2020) 45(3) Historical Social Research 288–313. See also: S Gupta, "Automated Text Classification Using Machine Learning" (*Towards Data Science*, 2018) <https://towardsdatascience.com/automated-text-classification-using-machine-learning-3df4f4f9570b> (last accessed 29 September 2023).

[74] N Baur et al, "The Quality of Big Data - Development, Problems, and Possibilities of Use of Process-Generated Data in the Digital Age" (2020) 45(3) Historical Social Research 209–43.

[75] Y Zhang et al, "A quantum-inspired multimodal sentiment analysis framework" (2018) 752(15) Theoretical Computer Science 21–40. See also: S Shiro, Research Report, Keio University, Dept. Math. KSTS/RR-18/002, 22 November 2018 <http://www.math.keio.ac.jp/academic/research_pdf/report/2018/18002.pdf> (last accessed 29 September 2023).

[76] F Arute et al, "Quantum supremacy using a programmable superconducting processor" (2019) 574(7779) Nature 505–10.

[77] S Aaronson, "Shadow tomography of quantum states" in *Proceedings of the 50th Annual ACM SIGACT Symposium on Theory of Computing* (New York, Association for Computing Machinery 2018) pp 325–38.

or hardware noise.[78] Quantum humanities may study the practical construction of norms, the power dynamics of their stabilisation and what these norms may tell us about classical data.

Reflections on *processes* may shed light on how quantum-enabled knowledge comes to be known. These reflections need not be informed by the minute details of the technology, but they may need general knowledge of the technology's underpinnings or the state of the art.[79] One of the most significantly different concepts of quantum technologies that digital technologies do not onboard is the link between quantum mechanics and the nature of reality. Ontological theories of nature resulting from quantum mechanics have significant implications for our understanding of space (teleportation[80]), time (time reversal algorithms[81]) and matter (quantum dots[82]). At its core, therefore, the study of the phenomenon is transdisciplinary work.

Reflections on new *knowledge* needs to focus both on the unique impacts of quantum computers and on the impacts quantum technology has when assisting other technologies. For example, quantum computers may render current encryption obsolete,[83] and they may also impact the use of systems of surveillance through quantum-assisted AI.[84] As a result, the epistemologies that are supported and changed by quantum technology could affect human coexistence and impact the humanities and social sciences. This dimension of new knowledge could bring us, for instance, to revise our models and assumptions regarding resources in game theory. This field also includes the measurement of success, such as the analysis of patents filed worldwide and the quality of those patents, as competition is a main force within this development.[85]

As noted above, quantum technologies may lead to reflecting on the ontology of nature, data and epistemology. This line of questioning makes quantum humanities different from digital humanities.[86]

For example, ever since the development of quantum mechanics in the early twentieth century, scientists and philosophers have intensely debated what quantum mechanics tells us about the nature of reality. One dominant view is the so-called Copenhagen Interpretation (CI), which proposes that reality is changed by human and non-human observation through the so-called wavefunction collapse.[87] The CI was first summarised by Bohr, Weigner and Heisenberg, who claimed it as an indisputable interpretation of reality

[78] X Gao et al, "Limitations of linear cross-entropy as a measure for quantum advantage" (2021) arXiv preprint arXiv:2112.01657.

[79] W Vogd, *Quantenphysik und Soziologie im Dialog – Betrachtungen zu Zeit, Beobachtung und Verschränkung* (Berlin, Springer Spektrum 2020).

[80] SLN Hermans et al, "Qubit teleportation between non-neighbouring nodes in a quantum network" (2022) 605 Nature 663–68.

[81] GB Lesovik, "Arrow of time and its reversal on the IBM quantum computer" (2019) 9 Nature Scientific Reports 4396.

[82] P Michler, "Verschränkt im Quantenpunkt" (2013) 12(1) Physik Journal 18–19.

[83] V Mavroeidis et al, "The impact of quantum computing on present cryptography" (2018) arXiv preprint arXiv:1804.00200.

[84] V Dunjko and HJ Briegel "Machine learning & artificial intelligence in the quantum domain: a review of recent progress" (2018) 81(7) Reports on Progress in Physics 074001.

[85] ZC Seskir and KW Willoughby, "Global innovation and competition in quantum technology, viewed through the lens of patents and artificial intelligence" (2023) 13(1) International Journal of Intellectual Property Management 40.

[86] Digital humanities are mainly described as a series of digital methods: Terras, supra, note 33. See also: Burdick et al, supra, note 33.

[87] HP Stapp, "The Copenhagen Interpretation" (1972) 40(8) American Journal of Physics 1098–116.

at the 1927 Solvay Conference.[88] This proclamation was so authoritative that different interpretations ("pilot-wave", proposed by de Broglie[89]; and "many-worlds", proposed by Everett and Deutsch[90]) remain largely understudied, even though they are consistent with experimental outcomes.[91]

Albert Einstein called the CI paradoxical and an "incomplete" theory as it violated the assumptions of realism and locality that Einstein's own theory of relativity rested on.[92] In 1964, physicist John Bell theorised an experiment – called an "inequality" – that, in 1972, proved that Einstein's assumption of locality is incompatible with experimental observations. However, Bell also realised that his inequality, while not validating the CI, constrained it to being non-local and non-real. That is, an object is perceived by measuring it many times, but it can never be seen as it *really* is.

Other interpretations, such as the pilot-wave interpretation, propose that reality exists, but we just cannot observe it directly – these are often called *ontological theories*. Recently, constructor theory has been developed.[93] Regardless of this discrepancy, the belief in quantum mechanics as an epistemic theory has impacted the way people see the world today.[94] If quantum mechanics as an epistemic theory is accepted, then what do we decide to know next, without looking for an objective answer but for a clearer vision of the future?[95] For some, the future is one without quantum computers[96]; for others, it is a future with quantum computers developed for only socially valued industries – such as

[88] JG Perillan, *Science between Myth and History: The Quest for Common Ground and Its Importance for Scientific Practice* (Oxford, Oxford University Press 2021). See also: G Bacciagaluppi and A Valentini, *Quantum Theory at the Crossroads – Reconsidering the 1927 Solvay Conference* (Cambridge, Cambridge University Press 2013).

[89] D Bohm, "A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables" (1952) 85 Physical Review Journal 166. See also: JS Bell, "On the impossible pilot wave" (1982) 12 Foundations of Physics Journal 989–99. See also: A Drezet, "Forewords for the Special Issue 'Pilot-Wave and Beyond: Louis de Broglie and David Bohm's Quest for a Quantum Ontology' (2023) 53 Foundations of Physics 62. See also: JWM Bush, "Pilot-Wave Hydrodynamics" (2015) 47 Annual Review of Fluid Mechanics 269–92.

[90] BS DeWitt, "Quantum mechanics and reality" (1970) 23(9) Physics Today 30–35. See also: H Everett, *The Many-Worlds Interpretation of Quantum Mechanics – A Fundamental Exposition by Hugh Everett*. Princeton Series in Physics (Princeton, NJ, Princeton University Press 1973). See also: D Deutsch, "Quantum theory as a universal physical theory" (1985) 24 International Journal of Theoretical Physics 1–41.

[91] D Wallace, "On the plurality of quantum theories: quantum theory as a framework, and its implications for the quantum measurement problem" in S French and J Saatsi (eds), *Realism and the Quantum* (Oxford, Oxford University Press 2019) pp 78–102. Please see latest developments here: <https://www.youtube.com/@ontheshouldersofeverett501/about> (last accessed 17 October 2023). See also: <https://www.youtube.com/watch?v=B2SSJmE0TeM> (last accessed 17 October 2023). See also: <https://www.constructortheory.org/> (last accessed 17 October 2023).

[92] A Einstein, B. Podolsky and N. Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" (1935) 47 Physical Review 777.

[93] D Deutsch, "Constructor theory" (2013) 190 Synthese 4331–59.

[94] A Zeilinger, *Einsteins Spuk – Teleportation und weitere Mysterien der Quantenphysik*, 13th edition (Munich, Goldmann 2007) pp 65–69. See also: M Jammer, *The Philosophy of Quantum Mechanics: The Interpretations of Quantum Mechanics in Historical Perspective* (New York, Wiley 1974). See also: R Skibba, "Einstein, Bohr and the war over quantum theory" (2018) 555 Nature 582–84. See also: M Schlosshauer, J Kofler and A Zeilinger, "A snapshot of foundational attitudes toward quantum mechanics" (2013) 44(3) Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics 222–30.

[95] Einstein et al, supra, note 92. See also: "Physics is an attempt conceptually to grasp reality as it is thought independently of its being observed. In this sense one speaks of 'physical reality'. In pre-quantum physics there was no doubt as to how this was to be understood. In Newton's theory reality was determined by a material point in space and time; in Maxwell's theory, by the field in space and time. In quantum mechanics it is not so easily seen." A Einstein, "Notes for an Autobiography" (*The Saturday Review of Literature*, 26 November 1949) <https://archive.org/details/EinsteinAutobiography> (last accessed 17 October 2023).

[96] E McKay, "'Keep the fight unfair': Military rhetoric in quantum technology" (2022) arXiv preprint arXiv:2203.01415.

healthcare – that are properly protected by the state.[97] For others still, quantum computers can be designed within markets as long as they produce human understanding,[98] public education,[99] solutions that accelerate the growth of corporations,[100] as a way to increase the safety of vulnerable individuals or as a means to secure a position in the international race for military development.[101]

Similarly, as such outcomes are probabilistically observed, what constitutes a result is socially constructed. For example, a quantum computer is used to solve problems by first running an algorithm in it and then making a measurement that collapses the wavefunction to a definite result. By repeating this experiment many times and collecting the statistics of the observed measurements, the experimentalist can discern patterns that can then be claimed to be answers to the problem that the computer was trying to solve. But for such a claim to carry weight, standards and metrics have to be socially constructed to establish a methodology of validation.

4. Development

In the context of quantum humanities, the development of quantum computing technology is an important area of study. This includes not only the technical aspects of the development of quantum computers, but also their creation, regulation and design,[102] as well as the broader social, cultural and political context in which this technology is being developed. Understanding the development of quantum computing can help us anticipate its potential implications and applications in the fields of the humanities and social sciences. It can also provide insights into the conditions of knowledge production and how science is influenced by societal factors.

This understanding can be useful for researchers and policymakers working in the field of quantum humanities, as it can help them make informed decisions about the direction and focus of their research and policy considerations. Technological innovation has always been a trigger for societal change. However, it is not an inherently logical and linear development process. Post-digitisation, although a driver of development, is characterised by mutual influence from the society in whose institutional framework it is located and the technology that exists or is being developed. The development of technology could serve as the first marker at this point because, of course, the development of technology could offer us the first clues as to its agency, to the classification of the implications being focused upon and also for reflection. Even though it is almost impossible to define a point

[97] ibid; T Dekker and F Martin-Bariteau, "Regulating Uncertain States: A Risk-Based Policy Agenda for Quantum Technologies" (2022) <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4203758> (last accessed 29 September 2023).

[98] "But I believe that the benefits may not only be in the material technologies that emerge, but also in the enlarged understanding that quantum ideas will bring; to put it grandly, these technologies will require the acceptance of some new concepts about the nature of reality." This quote points at how quantum science changes our understanding of nature and gives us a new understanding of our surroundings: DiVincenzo, supra, note 72.

[99] JR Wootton et al, "Teaching quantum computing with an interactive textbook" in *2021 IEEE International Conference on Quantum Computing and Engineering (QCE)* (Piscataway, NJ, IEEE 2021) pp 385–91.

[100] See, eg, IBM Institute of Business Value, "The Quantum Decade" (2022) <https://www.ibm.com/downloads/cas/Q5Q8ZOWR> (last accessed 21 September 2023).

[101] White House, "National Security Memorandum/NSM-10: National Quantum Strategy – National Quantum Initiative" (n.d.) <https://www.quantum.gov/strategy/#STRATEGY-DOCUMENTS> (last accessed 29 September 2023). See also: E Kania and J Costelllo "Quantum Leap (Part 1) – China's Advances in Quantum Information Science" (2016) 16(18) China Brief 11.

[102] C Coenen and A Grunwald, "Responsible research and innovation (RRI) in quantum technology" (2017) 19 Ethics and Information Technology 277–94. See also: KL Nousiainen and J Keski-Rahkonen, "Legal Business in the Post-Quantum Society" (*Legal Business World*, 6 September 2022) <https://www.legalbusinessworld.com/post/legal-business-in-the-post-quantum-society> (last accessed 29 September 2023).

zero in the development of a technology, important part of quantum humanities are visiting researchers at their laboratories and talking to inventors, developers or entrepreneurs. One work that can be cited on the development of quantum computers with a particular focus on their developers is the observational and reflection study by Werner Vogd.[103] He visited Anton Zeilinger at his laboratory and discussed how knowledge is created in sociology and quantum physics and what aspects such knowledge-creation processes share. This dimension of quantum humanities also encompasses questions about the conditions of knowledge production, be they legal frameworks for research or research acts, policies such as the project funding landscape and policy innovation management, how science is influenced by day-to-day practices, and so on. Anticipating what a technology might entail, how it might be applied and what meaning it might have one day can also be found in our paper because the step between application and implication is precisely the anticipation of what meaning an application will have for one's subject area. Development thus goes beyond the commercial application of technology as a point of investigation and consideration.[104]

In addition to studying the technological innovations in the field of quantum computing, the subfield of development should study the educational standards and institutions emerging in the field. As we have seen in recent years, industry leaders[105] and enthusiasts have started developing education approaches and credentials to solidify career paths in quantum computing programming. These education approaches as well as those being independently developed by institutions (eg quantum science and engineering (QSE) PhDs with quantum computing specialisations) around the globe will prove critical to supporting development in these fields.[106]

Quantum computing is viewed as a technology with the potential to perform specific tasks in very different scientific fields. To determine the implications of quantum computers, experts rely on their knowledge and insights to envision these possibilities. They ascribe meaning to the object of a quantum computer. This initial stage sets the course for future developments, though the meaning of an object can always be reinterpreted.[107] The assignment of meaning to an object will have effects on the societal embeddedness of the quantum computer. The quantum computer is developed by people who live in our midst – they often share general basic assumptions about our lives, culture and so on.

Therefore, the development of this technology, as well as the use of it, is of interest to quantum humanities. The development of scientific and technological ideas, inventions and discoveries and the associated social and cultural contexts are topics of historical studies, cultural studies and so on, as cultural dimensions of technology development and the influence of cultural identity on technology development are also addressed here. In addition to the utilisation of technology, there is the process of technology development, which occurs before its implementation and involves active participation. Within the legal sciences, especially legal theory, the fields of law and ethics are linked in such a way that moral questions and responsibilities in connection with technology development, ethical guidelines and principles for the responsible development of technology are developed

[103] Vogd, supra, note 79.

[104] F Bova, A Goldfarb and RG Melko, "Commercial applications of quantum computing" (2021) 8 EPJ Quantum Technology 2.

[105] IBM Certified Associate Developer – Quantum Computation using Qiskit v0.2X <https://www.ibm.com/training/certification/C0010300> (last accessed 29 September 2023).

[106] Example program of QSE at Harvard University <https://seas.harvard.edu/news/2021/04/harvard-launches-phd-quantum-science-and-engineering> (last accessed 29 September 2023).

[107] A Powell, "Harvard weighs in on Google's Quantum Supremacy" (*Harvard Gazette*, 29 October 2019) <https://news.harvard.edu/gazette/story/2019/10/harvard-weighs-in-on-googles-quantum-supremacy/> (last accessed 21 September 2023).

and discussed. Since political science emerged from the study of constitutional law, references to political science can also be found here. Technical innovations have dynamics, and their developmental steps are the results of cultural actions.[108]

Lastly, the development subfield must also explore the concept of convergence between quantum computing and traditional digital tools. Because quantum computers are not being developed in a technological vacuum, advances in graphics processing units (GPUs), machine learning, high-performance computing systems and traditional system architectures are bound to affect their development, as they all continue to develop simultaneously. Additionally, industry itself is moving towards hybrid classical and quantum systems to incorporate "the best of both worlds" when solving the problems of tomorrow. This can clearly be seen by the emergence of the quantum processing unit (QPU), in a similar fashion to the integration of GPUs in the modern architecture. Moreover, the idea of convergence is supported by national governments, as is exemplified by the creation of NASA's quantum and AI laboratory, which aims to demonstrate the utility of quantum machine learning.[109]

IV. Quantum humanities: a research programme

The proposed research programme for quantum humanities includes four key elements: (1) the application of quantum computing to address questions in the humanities; (2) reflection on the methods and techniques of quantum computing; (3) the evaluation of quantum computing's potential societal implications; and (4) an examination of the development processes and ecology of quantum computing. By focusing on these elements, the research programme aims to explore the potential of quantum computing to advance our understanding of the humanities, as well as to consider the technology in society. Through this programme, researchers in the field of quantum humanities can develop a deeper understanding of the capabilities and limitations of quantum computing and use this for research and decision-making. Further investigation of the significance of quantum computing will probably involve a combination of research in the fields of quantum mechanics, computer science, the humanities and the social sciences. This research will probably involve the development of new quantum algorithms and techniques for solving problems in these fields, as well as the study of the potential societal implications of quantum computing. It will also probably involve collaboration and dialogue between researchers from different disciplines to develop a deeper understanding of the potential of quantum computing to advance our understanding of the world.

To facilitate this research, it may be necessary to establish dedicated research programmes and funding opportunities for scientists working in the field of quantum humanities. This could include the development of interdisciplinary research centres and networks, as well as the creation of opportunities for collaboration and exchange among researchers from different fields. While creating these opportunities, it is inevitable that certain hurdles in their implementation will come to light. Important among these is how to develop a common vocabulary for such an interdisciplinary field. This problem has already been tackled in quantum computing itself when joining computer scientists and quantum physicists within the same field. Due to the even greater range of fields inside quantum humanities, a common glossary as well as a keen understanding of the underlying tenets of their most basic components (so that they can

[108] Rammert, supra, note 11, 16.

[109] See QuAIL's mission on its website: <https://www.nasa.gov/content/nasa-quantum-artificial-intelligence-laboratory-quail> (last accessed 21 September 2023).

be understood by all members; eg ethics, qubits) must be created as we move forward in the field.

Building upon the concepts and principles of quantum humanities, we present the following theses encapsulating the key dimensions discussed in this paper.

1. Theses on quantum humanities

(1) Quantum mechanics could affect our understanding of time, distance, space and information transfer, leading to ontological, constructivist and epistemological changes. Quantum humanities aims to incorporate these changes into its research concepts, moving away from predetermined notions and embracing a transdisciplinary view.

(2) Quantum humanities aims to apply the principles and concepts of quantum mechanics to study and understand various aspects of human culture, society and knowledge. Technological innovation and use are intertwined with cultural practices, social understandings and everyday actions.

(3) Quantum humanities reflects on the historical–social processes that lead to the acquisition of understanding of the world through quantum theories and technologies and explores how knowledge is generated through these technologies.

(4) Similarly to quantum mechanics, quantum humanities proposes that the world can only be epistemologically understood, and thus no stable version of what the world *is* exists outside of human action and interpretation. We call into question any claim of objectivity in data, algorithms, technological development or human action.

(5) Quantum humanities differs from digital humanities, which primarily focus on the use of digital technologies in humanities research, by emphasising the qualitative value derived from quantum mechanics in addition to the use of quantum technologies in humanities research.

(6) The applications of quantum technology in quantum humanities extend beyond the use of quantum computers as research tools. Quantum humanities recognise that computation and survey strategies are changing, leading to a new approach that impacts society and research in the humanities and the social sciences. The choice of methods in quantum humanities must remain open as observations inevitably impact reality.

(7) Quantum humanities acknowledge the emergence of a new set of quantum technologies and their potential for disruptive innovation. They recognise the birth of new machines, processes, cultures, activities and knowledge. Therefore, they explore the possible implications of quantum technologies and the possible impacts of these changes. Yet the development of concepts in quantum humanities extends beyond specific fields of social regulation, such as ethics or politics, to encompass broader contexts and interconnections.

(8) Quantum humanities critically question the assumption of a revolutionary future through quantum technologies or that these technologies can enable a "good" future that can be achieved through study, seeing in this an illegitimate stabilisation of a particular vision of the future through science, potentially entrenching certain normative views. Quantum humanities argue that such claims obscure the uncertainty of pursuing such visions of the future. They emphasise the need for a holistic, reflexive and symmetrical research programme to analyse how quantum technology is influenced by different social actors, institutions, cultural practices and human exchanges, and vice versa.

(9) Quantum humanities acknowledge that quantum technologies do not develop in a vacuum, and that they will be tied to other emerging technologies. As such, our studies must take into account this convergence and equally converge with other fields that shed more complete light on the objects of study.

Acknowledgments. Above all, we would like to express our most sincere and gracious thanks to Zeki Can Seskir of the Karlsruhe Institute of Technology. Without his comments, input and discussion, this paper would not have been possible. We also would like to thank Johanna Barzen, who initiated this work through conversation.

Competing interests. The authors declare none.

Cite this article: A Bötticher, J Hernandez, MC Kettemann, V Gast, and R Araiza Bravo (2023). "Introducing a Research Programme for Quantum Humanities: Theoretical Implications". *European Journal of Risk Regulation* **14**, 435–456. https://doi.org/10.1017/err.2023.71