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European Quantum Strategy – Global and Local Consequences

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Abstract— **Europe has to face strong competitive challenges in the field of QIT from other regions of the world. The tools for the effective implementation of the challenges related to the start, we hope, of building a quantum civilization are both common and individual in particular European countries. Joint projects in the field of QIT, usually narrowly focused, are announced by large European Agencies and are related to their activities. Large-scale collaborative projects are of course the domain of the EC. National projects depend heavily on the capabilities of individual countries and vary greatly in size. The most technologically advanced European countries invest hundreds of millions of Euros in national QIT projects annually. The largest European FET class project currently being implemented is the Quantum Flagship. Although the EQF is basically just one of the elements of a large and complicated European scene of development of quantum technologies, it becomes the most important element and, in a sense, a dominant one, also supported from the political level. There are complex connections and feedbacks between the elements of this quantum scene. National projects try to link to the EQF. Here we are interested in such connections and their impact on the effectiveness of QIT development in Europe, and especially in Poland.**

Keywords— **QIT quantum information technologies; quantum computing and simulation; communications; sensors; metrology; European Quantum Flagship**

I. Introduction

SEVERAL large quantum initiatives and projects are under implementation in Poland, such as QuantERA, NLPQT or MIKOK. Several consortia and companies are building their quantum processors. Numerable university laboratories open strictly technical programs related to hardware and programming experiments for QIT. Several university groups, for example in Gdańsk, Kraków and Warsaw, have been successfully conducting coordinated advanced research on the information aspects of quantum mechanics for many years. The emergence of the European Quantum Flagship EQF [1], which is the biggest class of the EC Future and Emerging Technologies FET initiatives, changes the geometry of activities in the area of QIT in Europe, including Poland. The article presents selected problems related to the organization of the area of quantum technology and innovation in Europe and some local consequences of these global and local actions. The European QIT is presented on the the background of some currently solved technical issues of QIT, crucial for quantum teleinformatics,. The article is also published in Polish in Elektronika, a Monthly Journal for engineers [2].

Almost all of quantum sub-disciplines making up the whole of QIT are developing so fast that they begin to acquire their own research and technological specificity. Their physical foundation is the development and experimental or market availability of components, devices, processors, circuits, and even entire, ready to use, functional quantum systems. For some of these devices and systems, the theory has far surpassed the technology, and in these cases we know quite precisely what is missing and what we still cannot do to make the quantum layer show its potentially significant advantage over classical solutions. This is the case with simple quantum networks and quantum computing. There are excellent algorithms, but they are currently unsolvable.

However, the situation is more complicated, because in some cases the technique and experimental applications have been ahead of the theory, in some sense, and under certain assumptions. Quantum teleportation and entanglement switching, as well as the common provenance of quantum coherence and entanglement are the technical foundations of quantum teleinformatics. We are still a long way from fully understanding the universal nature of non-locality, not just the quantum non-locality already exploited by technology. Such multilaterally entangled quantum states as NOON, GHZ, and W are used to build quantum practical systems. In such and similar quantum magic systems we must perform a continuous/periodic entanglement distillation or ZENO reset, otherwise realization of quantum functions in our noisy thermodynamic environment is impossible.

Bell's theorem and inequalities prove the nonlocality of quantum coherence and lay the foundation for magic states and entanglement. The Gottesmann-Knill theorem defines the area in which it is impossible to simulate such quantum states by classical methods, and thus the potential area of the strict advantage of quantum circuits. In the QIT space, quantum contextuality is considered as such a magical ingredient. This was indicated by the Kochen-Specker theorem very early in 1967. This is the second of the functional foundations of quantum resources. More and more relations between quantum nonlocality and contextuality are known. Are there relationships and rules more general than quantum mechanics? Without knowing such rules, are we able to technically master the manipulation of quantum resources necessary to implement the functionalities we expect? Practice shows, not for the first time, that we implement practical functionalities without knowing the rules exactly. And what we need here and now is secure telecommunications, quantum solving of classically NP-hard problems, simulations of classically unsimulated phenomena, detection and measurement of signals at the quantum level, well below the current classical possibilities.

The era of QIT timidly began with Bell's inequality and its numerous modifications like the CHSH, ideal for testing initially in the laboratory and now globaly. Without theoretical and next numerous experimental evidence of violation of Bell's inequality, which is the boundary condition of local realism,

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there would be no subsequent development of QIT. Strong laboratory proof of the nonlocality of quantum mechanics was needed. Such evidence has been provided in many measurement architectures and contexts. Evidence has been provided even in social and cosmological contexts. An aspect of the tests of the non-locality principle, of causally correlated quantum objects in general, and in our case of entangled transmitted qubits, is the relativity of simultaneity. In general, simultaneity depends on a moving inertial frame of reference. For causally related events, the order of priority, including simultaneity, is preserved in all frames of reference. Can this feature be functionalized for quantum resource testing? There are many more such fundamental scientific and technical questions related to the development of QIT. If the functionalization of quantum phenomena is to accelerate, and if there is a broader consensus that QIT is the next potential generation of the information layer of the knowledge society, then the whole area should be well coordinated on the widest possible scale.

CHSH tests are statistical and correlational in nature, therefore it is important to carry out the experiment, e.g. teletransmission with photon polarization, or stationary with particle spins, and carefully close all possible measurement gaps. The most important of these gaps are the gap of locality, measurement integrity (sampling) and determinism – freedom of choice. These gaps have a different reference in the research aspect, related to implementation of quantum functionalities at the functional technical level. In the research aspect, the perfect removal of gaps means an increase in the accuracy of the proof of non-locality of quantum mechanics, and thus a more accurate determination of the boundaries of the area of validity of this feature as a permanent property of the Universe.

Knowing these boundaries is important because it translates into applications in the future. In addition, the blurred line between the quantum world and the thermodynamic macro world in which we live and in which our applications, such as QIT, operate, is one of the most important. Somehow, through the quantum selection of these ones and not the other quantum decoherence processes, a macro world emerges from the quantum world. The shape of our world is determined by the rules of quantum choices that govern the decoherence processes. Some quantum systems undergo faster decoherence than others. Why is this happening? We want to master quantum decoherence and employ the more thoroughly known to build the otherwise complicated Quantum 2 era, equipped with good knowledge of the Quantum 1 era.

In an isolated quantum world, coherence and superposition are permanent, while in our thermodynamic world they are fleeting and fragile. One-way and many-way quantum coherence is the most precious essence, the subject of the current quantum gold rush. These two features, coherence and superposition, are closely related. In order to functionalize them to the QIT form, we learn their basic characteristics and behavior in the macro world, their lifetime, coupling channels with a thermodynamic bath, we learn how to manage them, distillation protection against noise, transmission, switching, replication, etc. All these operations on coherence and quantum superposition must take place within hard constraints imposed by quantum prohibitions resulting from the Heisenberg uncertainty principle, limited speed of light, limited energy, subatomic quantum rules, etc.

II. Characteristics of QIT Environment

The QIT technology is based on quantum measurement, reducing the coherent state of the qubit to the classical macro state. Measurement is one of the decoherence channels, here the intentional one. The Nature also measures the quantum system (in our case, the qubit) through various decoherence channels. Such a measurement process seems to be a simple issue, but it is not. The process of quantum decoherence is generally a very complicated phenomenon. What are the three main measurement gaps important for the functionalization of quantum phenomena? In technical terms, it depends on the type of functionality considered and means for quantum telecommunications, a reduction of the possibility of easy external interference allowing enemy resource management. For quantum random number generators means increasing the depth of randomness. Quantum randomness in the technical practice of quantum systems depends on many factors, such as: type of qubit (natural or synthetic), type of volatile qubit source, distinguishability/indistinguishability of qubits, contextuality, entanglement99 etc. Discrimination of qubits by not approved user can be a disaster for a quantum teletransmission system. We use the Hong-Ou-Mandel HOM and Bell tests for testing.

In examining the measurement gaps of the Bell tests, we treat Nature somewhat as a trickster trying to outsmart us and hide from us the true nature of non-locality. In fact, we are rather those hackers trying, albeit in good faith, to steal quantum secrets from the Nature. Implementation of a perfect quantum measurement system is impossible, so the true nature will remain hidden to some extent. We may be dealing with a real impostor in the technical solution of a quantum system transmitting valuable, confidential information. But he is also imperfect, he performs his unauthorized test on our system in an imperfect way, so he is easier to isolate if only we have the appropriate knowledge. All measurement gaps in quantum QIT systems must be properly closed, otherwise we have no authority to call the system truly quantum safe.

If the functional system works in the area of local realism, even using quantum technologies, we are basically dealing with the Quantum 1 era all the time. QIT is the Quantum 2 era, which requires meeting a positive non-locality test. The locality gap, checking whether the system does not meet the requirements of local realism, requires such a configuration of the experimental research equipment or the architecture of the functional system that the information carried by photons or particle spins is not exchanged between the relevant detectors. This requires exact fulfillment of two conditions. Firstly, the detectors must be separated from each other by such a distance that the potential exchange of information between them would be completely impossible, or it would require transmission of signals at superluminous speed. This requirement is met by enclosing the optical signals in a fiber of appropriate length.

Secondly, the configuration of the statistical correlation measurement system (in the technical solution, the architecture of the optoelectronic receiver) must be random and change quickly enough in a completely statistical way between successive measurements. Then, the possibility of communication between both detectors and signal transmitters and the potential knowledge about the measurement results and the architecture of the transmitters and detectors are eliminated. Otherwise, the local realism model can still explain the measurement results, even if Bell's inequality seems to be broken. If changes in the system architecture are not random, the knowledge of this can reach the source and detectors so that the system reconfigures itself and one detector can affect the other and the source generating a pair of entangled photons. As a result, correlation statistics are set not by chance but by a knowledgeable system.

The fair sampling vulnerability is related to the fact that no measurement process accurately detects all individual photons. It is a statistical process. If too few photons are detected during the measurement, the set of detected particles may become an unrepresentative sample, artificially distorting the correlation statistics. In a quantum transmission system that does not provide fair sampling properties, the hacker (or deterministic measurement system) is free to shape the correlation statistics to his advantage. A perfect closure of this gap is impossible, because it is impossible to perfectly detect all photons. However, it is possible to significantly reduce this gap. The possibilities of externally influencing the statistics are reduced as the received photon statistics increase. The degree of danger can be calculated theoretically and with a reception level of over 80% of photons, the external influence is technically very difficult, in practice impossible.

The freedom of choice gap is related to the history of the quantum measurement system (generally a quantum functional system, including QIT). From a technical point of view, if a quantum QIT system does not have freedom of choice, then this feature can be discovered by a hacker and used for effective operation. A quantum system has no freedom of choice if it is static with a fixed signal and topological architecture, if it is not statistical and has no free choice of its own configuration. A quantum system also does not have full choice if it is in ongoing historical coherent relationships between its internal parts - the source and detectors, and even the transmission channel (as a component of the system that performs a quantum operation). Such ongoing historical entanglement during the execution of new series of functional operations by the system and during measurement has a fundamental impact on the result of correlation statistics, it can be decisive and be intentionally distorting or be deterministic to varying degrees. The architect or operator managing such a historically quantum correlated system (entangled or set appropriately contextually) can practically arbitrarily set the results of its operation.

In the extreme case, the freedom of choice gap concerns the problem of setting all the parameters of the Universe at the moment of the Big Bang. Hypothetically, all initial and boundary conditions are set at the zero point. In a less extreme case, it may concern the setting of parameters in the selected Sector. The idea of super-determinism means that without going beyond the System, we can't do anything. The universe arranged in this way is subject to the law of local realism, naturally at the expense of, among others, free will. So far, the suspicion of super-determinism, hovering over our civilization like the sword of Damocles, has been experimentally shifted back in time to more than 10 billion years. Zeilinger's team performed a series of Bell inequality tests using photons from two different distant quasars. At the same time, efforts were made to remove all measurement gaps as carefully as possible.

Due to the large number of subtleties of quantum phenomena, and there are many more subtleties than mentioned above, and the need for algorithmic translation and practical adaptation of these subtleties to technological situations, the implementation of QIT is a very complex process and will undoubtedly take decades. Also due to the complex nature of quantum measurement, there are more possible measurement gaps in QIT systems. Without the simultaneous and most careful closing of all measurement gaps also in practical, and not only scientific, solutions of QIT systems, they will not work as expected. They will be susceptible to relatively easy, harmful external influences. Another example of such subtlety is the impossibility of direct mutual translation of relatively simple, or rather the simplest, tripartite quantum states W and GHZ. They represent, in a sense, other, non-transferable types of entanglement. The node of the future quantum network will have to deal with such conversion problems. The most important computational problem in the network node will be solving the problem of quantum signal multidimensionality. This problem is NP difficult and there is no analytical solution, currently also in the space of quantum computing. Approximate calculations use analytical geometric methods of multidimensional polyhedra and their symmetry properties.

Further examples of potentially difficult-to-manage quantum subtleties include the quality of the QIT system's classical and quantum randomness, qubit indiscernibility, and sub-Poisson statistics of single volatile qubits. The ability to statistically distinguish and identify qubits in a quantum functional system is an example of a wide open door to arbitrary manipulation of the transmitted information. Another example of subtlety is the monogamy of quantum entanglement resulting from the non-cloning prohibition. Entanglement cannot be shared freely among any number of qubits. Two maximally entangled qubits cannot be entangled simultaneously with anyone else, i.e. with the third qubit. In general, with the multilateral entanglement required for the construction of quantum networks, two weakly entangled qubits can be entangled with a third one by satisfying the CKW (Coffman-Kundu-Wooters) inequality, which imposes limits on the allowable entanglement strength. In determining this force, the concepts of quantum concurrence, which is an invariant constant for a qubit, and entanglement monoton, which is a function of the amount of entanglement residing in a given quantum state, are used.

At the current stage of development of the QIT functionality, like quantum teleinformatics, we use the simplest tool of this technique, a qubit - two-level quantum object. The qubit allows for a lot, the implementation of the simplest quantum key distribution algorithms for the purposes of secure communication, the construction of simple quantum communication links with teleportation and switching of quantum resources, the execution of some quantum algorithms in a quantum NISQ class processor, which do not require too much resources so far, etc. It will be necessary to use multi-level quantum objects in the form of qudits. And the road to qudits leads experimentally through qutrits and quaquarts. What does this mean for QIT? A quantum network node must be able to accept multidimensional quantum information. This cannot be done in a simple qubit architecture. The simplest fault-tolerant qubit logical architecture requires the use of five physical qubits. Quantum error tolerance functionality consists of detection and recognition the error syndrome. Only on the basis of such a diagnosis can corrective or preventive actions be taken. A quantum network requires multipartite interactions, not just twopartite like the quantum links between Alice and Bob. Multipartite networks require mutual multipartite quantum correlations. Multipartite entanglement is completely different from bipartite one. This is a completely different category of correlations requiring quite different methods of analysis and management.

In telecommunications channels and networks, we use volatile qubits or only transfer their quantum states by teleportation and entanglement swapping. In quantum processors currently of the NISQ class, we are dealing with stationary qubits, e.g. trapped atoms and ions, NV color centers in diamond, superconducting planar transmons, etc. The remarks on the role of dangerous gaps and quantum subtleties apply to all these devices and systems of computing, transmission, storage and quantum information processing, quantum detection and remote sensing. If the designer does not address the problem of quantum errors, gaps and subtleties in the processor, it may be practically useless. A completely different situation occurs in research solutions. There, it is necessary to test the possibilities of limiting the propagation of errors in open qubit architectures, preventing the possibility of hacking the quantum system, testing quantum decoherence channels, testing the possibility of distilling quantum resources in different architectures, etc.

III. Quantum Self-Organization of Europe and Poland

There are several obvious reasons why the European scientific, research, industrial as well as political communities are making organizational efforts to create various types of broader transnational coordination bodies regarding quantum information technologies. One reason is the very strong technological competition from the US and China. IBM offers a universal, quantum, open cloud service, with an excellent Quiskit user interface, using several hundred-qubit transmon processors. IBM and Microsoft clouds, offer quite advanced possibilities of quantum computing for research and teaching purposes. Commercial computing services are also offered, as well as quantum key distribution QKD services. Such services will be expanded and further commercialized.

Global investments in QIT, currently in the tens of billions of Euros per year, include major government and regional projects, development initiatives by major industrial players, numerous highly concentrated corporate innovation activities, many academic laboratory activities, launching new quantum products, economic activities in QIT of investment companies, etc. Europe also actively participates in such development and economic activities. However, there is a difference between Europe and the USA and China. The strength of Europe is science and academic education. In Europe, however, there are no giants such as Google, Microsoft, Meta and IBM, and giants such as Chinese government consortia, which are absolute industrial leaders also in the field of QIT. They make up the quantum ecosystem. It is around them that a permanent new quantum technological and social layer is created, which has a chance to form the nucleus of a new civilization foundation. In large company laboratories, quantum technology is being developed to a level that cannot be achieved in academia and SMEs. Perhaps this is missing in Europe? Can the massive QIT development program announced as the European Quantum Flagship EQF be able to compensate for such a lack.

Another reason for the significant intensification of activities in the area of QIT is the standardization of quantum products and services on a global scale. It is hard to imagine that Europe would not be involved in global QIT standardization processes. However, if Europe didn't take it, would we condemn ourselves to the grace of better, faster and stronger? We'll have to take the standards from them, and it's already starting to happen. Standardization processes are absolutely global in nature and their participants at various levels of work are rather global enterprises, scientific and industrial consortia, scientific and technical and political organizations, and generally large geographical regions. It is necessary to self-organize and delegate appropriate bodies to work at various levels of advancement of quantum standardization processes.

Another reason, no less important, is the need to educate quantum technology staff both at the level of theory and software as well as technology of quantum components and systems. Quantum technologies are diametrically opposed to classical ICT technologies, and often not physically obvious, so staff training is not a trivial issue. Universities will probably undertake, have already undertaken, such education, but support in the form of clear organizational pan-European activities in this direction will greatly facilitate the appropriate decisions of academic and industrial circles, as well as encourage candidates who see their place of scientific career and work in this area more clearly.

If we already recognize today, perhaps a bit exaggeratedly, that quantum technologies can potentially significantly change the functioning of the future knowledge-based information society, then all the above-mentioned reasons are very important and can be said to be immediately enforceable. Therefore, European quantum technology communities undertake a number of large initiatives regarding, for example, global research projects, construction of large experimental and industrial infrastructures, as well as related to the education of designers, technologists, operators and users. Systematically implemented QIT will slowly create a new information layer of the society. Such a layer will require new staff in Europe and in Poland at all functional levels. It is necessary that Poland also participates in these initiatives, not once there, but from now on.

Large developmental European initiatives have significant funds allocated by competition. So what are the local chances of participation if we start a bit later? And if we do not belong to the core initiative groups. It depends on the European policy and the type of time horizon adopted - short-term or long-term. Does Europe have a chance to create a research and industrial QIT center of global importance? Will Europe expand the front in which is a leader, relatively evenly across potential resources? Or is it rather about strengthening the core that currently has a chance to effectively take up global competition, at least in the research, academic and innovative areas? In these areas, the European core is a world leader.

Is there an adequate QIT quantum engineering environment in Poland that can make specific commitments as part of a wider European initiative? It seems to be, but is it properly organized to create a critical mass perceived by the initiators as an adequate representation? It's not just about scientific representation, which we have excellent, but also technical, economic and business representation. Will it not end with the participation of individual small local national teams glued to individual larger initiatives, currently of the RIA type? This has been the case most of the time. There is nothing wrong with that, glory to very good and active national teams, but this is not how you build a larger sustainable ecosystem. The ecosystem is built now by others. We help them. Only if it exhausts the ambitions of our scientific and technical communities, and in the longer term, the innovative and economic ones? In Poland, there are several very advanced theoretical teams working in the field of basic research on QIT. In Poland, there are also several excellent domestic innovative companies that can take up technological challenges, but compared to the European reference, this is only the scale of SMEs.

IV. European Quantum Flagship and its Anchoring in Local Initiatives

European development initiatives FET - Future and Emerging Technologies are the largest tools at the disposal of the EC as part of the implementation of the framework science, technology and innovation policy. The European Quantum Flagship EQF is the third FET project of this scale after the graphene and human brain projects. Formally launched in October 2018, it will be implemented and financed at the level of EUR 1 billion by the EC for a decade. The scale of the project is determined by such parameters as: the expected number of European researchers in the cooperating countries involved in the project should exceed 5,000 people, the total number of research and innovation projects/activities launched within a decade and referred to in EC terminology as RIA - Research and Innovation Actions should reach 140. The currently used term RIA is an extension in relation to separate projects and an extension of the category of JRA - Joint Research Activities previously used in framework projects. In other words, the RIA represents the number of assumed quantum projects of various types to be launched under the EQF financial umbrella and approximates the expected financial policy of the EC regarding the distribution of significant total EQF funds among individual large applications of research and innovation initiatives. The largest RIA submissions will be in the order of 10 million Euros. RIA project applications are collected and approved during periodic competition calls announced by the EQF.

Looking from a distance at the EQF initiative, which concerns the areas of science but at the same time very strongly at innovation, one can clearly see the pro-social and pro-economic pressure on the development of quantum information technologies. This pro-community approach is expressed through the promotion of mainly applied research, the maximum possible involvement of industry and innovative companies in such research, and the active search for social acceptance for such actions. Basic research is by no means omitted, however, thematic sections that are missing for the efficient implementation of certain key application tasks seem to be preferred. The priority directions of such tasks are set out in the EQF assumptions, with a certain margin of acceptable changes within a decade, resulting from scientific and technical progress.

Such a large centralized initiative as the EQF has a significant impact at the pan-European and local national level on scientific, innovative and strictly economic application activities. The EQF is a kind of magnet, an attractor that pulls in other types of relevant initiatives. It can even be said that the qualitative and quantitative mass of such global and local initiatives attracted to the EQF's area of influence is a good indicator of the maturity of quantum technologies and their readiness for much wider applications and social acceptance. Such a way of influence of large European central initiatives has already been quite well tested in other areas of advanced technologies with high application potential both in science and innovation. Massive European projects can be mentioned here in areas like photonics, sensors, cybersecurity, particle accelerators, etc. The results of these projects have produced amazingly positive results in the areas of innovation and economics. Similar hopes are attached to the powerful EQF initiative. We still have to wait a bit for the assessment of the impact of the EQF on the innovation and economic environment in Europe. The first observations and results are very encouraging. Such a positive impact of the EQF is also quite strongly felt in Poland.

The aim of the European initiative is, as stated in the EQF documents, to retain scientific leadership, kick-start the European QT industry and accelerate market take-up. With regard to large new technological trends, such as QIT, there are three required factors determining, in a global sense, the potential social and commercial success. It is necessary to demonstrate at least a few relevant examples of the use of technologies with significant market potential. The level of advancement of technology and innovative activities behind these examples must ensure the possibility of large-scale activities. A sufficiently broad and deep front of research activities is a dynamic scientific foundation on which the two economic factors are based. These two required economic indicators of technology maturity are supported by two scientific and financial pillars. The role of the scientific pillar in such a system of implementation of a new, massive and key technological ecosystem, which is QIT, is to efficiently solve the current scientific and technological limitations encountered through constant changes in the area of application development and production of pilot applications. This scheme is widely known. This is how leaders in mature mobile telephony and other large innovative sectors operate. In the QIT area, we have a completely new area to be developed.

Such a massive initiative as the EQF cannot hang in a technological and economic vacuum. It must be properly anchored in local and national activities, and be preceded by progressively expanded transnational precursors. The EC public data on aggregate Community funding of the QIT sector in the 20 years preceding the EQF lists a total of EUR 500 million in the EU FP and ERC framework projects. Among such completed projects, one can mention, for example, QUROPE implemented in 2013-2017 as part of FP7 and its legacy in the form of a useful Quantum Information Processing and Communication in Europe QIPC portal [3]. One of the results of such coordination activities was the publication in 2016 of the Quantum Manifesto, signed by over 3,500 scientists, including numerous representatives of Poland, regarding the establishment of the quantum FET project.

An important national and international initiative, QuantERA, launched by the Polish National Science Center in 2014, later resulted in the European project launched in 2016 and implemented in two phases, currently the second phase of QuantERA II, launched in 2021 with the participation of 39 institutions financing science in the QIT field from 31 countries [4]. The coordinator of the network is University of Warsaw. This initiative perfectly adds to the building of the European quantum technology community and laying the foundation for such massive actions as EQF. Design competitions announced by QuantERA were held in 2017, 2019 and 2021.

The National Center for Photonics and Quantum Technologies NLPQT is a consortium composed of the country's leading research units in the field of quantum technologies - UW, PWr, IF PAN, NCU, UJ, UG, UŁ, and CFT PAN. NLPQT is also a project implemented with national and European funds. The current stage of the project is being implemented in the period 2019-2023. The project coordinator is University of Warsaw [5]. The construction of such an advanced laboratory of photonics and quantum technologies is an excellent way to create a more durable foundation for the implementation of further major projects in the country on an international scale. The project will lead to an increase in the innovativeness of the Polish economy, significant development of the science sector and development of cooperation between enterprises and scientific institutions. In the project, the PIONIER network will be used to test innovative solutions in the field of quantum cryptography.

Scientific institutions from Poland such as PCSS in Poznań, Pionier, the Institute of Bioorganic Chemistry of the Polish Academy of Sciences, Creotech Instruments S.A., CFT PAN, CAMK PAN, ACK Cyfronet AGH and others take part in large European initiatives like EuroHPC, EuroQCS regarding the construction of a common quantum computing and communication infrastructure in Europe. Some of such infrastructure is built in the country. One of the quantum computers as part of EuroHPC is implemented at the IChB PAS in Poznań. Another quantum computer implemented as part of the MIKOK university-industrial project is being implemented at the CEZAMAT center of the Warsaw University of Technology.

Today, EQF, also thanks to all such actions, is the result of, among others, Quantum Manifesto and the continuation of QUROPE. The EQF guarantees the amount of EUR 1 billion in the decade 2018-2028 plus collateral funds declared by the beneficiaries. So the sum will be much larger. The currently available products of the quantum QIT technology sector are still expensive, relatively complex, quite poorly adapted to the requirements of the mass market, they show an advantage only in very specific applications. At this stage of development, however, they arouse considerable interest in security and defense markets. In other words, we will not have public, secure, quantum network communication at our individual public and private disposal for a very long time, rather in the horizon of decades. The EQF is to shorten this time horizon through the best possible coordination of the regional collective effort.

As for national activities in Europe, on the basis of which joint activities are usually organized, the most active centers are, for example, in Germany, e.g. Max Planck Institutes of quantum physics, quantum optics, quantum materials, Julich Center, etc., as well as in the UK, France, Italy, Spain, etc. An example is the Quantum Communications Hub organized in 2014 by four universities in Birmingham, Glasgow, Oxford and York. The internet hub is organized around the UK's national QIT development programme. The goal of this program, currently being continued in the next phase of funding in 2019-2024, is to translate quantum science into a major area of development of commercialized technologies. QC Hub has been expanded to include more academic partners, the universities of Bristol, Cambridge, Herriott-Watt, Kent, Queen's Belfast, Sheffield, Strathclyde, and numerous industrial and public partners such as NPL. The given example is representative of the importance attached to the development of QIT in these countries.

One of the most interesting aspects of such national actions is that they offer attractive and practical, implementation topics for doctoral dissertations and employment for young scientists. National funding in these leading countries is at the level of hundreds of millions of Euros per year. National initiatives are complemented by project financing by international agencies operating in Europe. Such initiatives have been undertaken, for example, by the European Union of National Metrology Institutes EURAMET, the European Space Agency ESA, the European Defense Agency EDA, etc. An interesting Swiss proposal formulated by GESDA is the establishment of the European Open Quantum Institute. The QuantERA initiative, coordinated by Poland, plays a very positive role in this rather complex landscape of coordination of funding and research.

The first call for projects to the EQF was announced in autumn 2017 with a budget of EUR 130 million. In the field of quantum communication, the topic of development and implementation of cheap, compact and much more secure quantum random number generators, components for quantum telecommunications systems with a continuous variable, and assumptions for the construction of a pan-European quantum Internet network were addressed. In the field of computing, projects were undertaken to build quantum processors with the number of physical qubits over 100. The next competition in this area concerned the construction of a test quantum key distribution network covering an area of more than 40 km and implemented in metropolitan conditions. The test is to be a pilot for the potential construction of such a network on a pan-European scale in the future.

In EQF Poland is present through its representatives in various places of this pan-European initiative. The European Quantum Community Network (QCN) has members from Poland representing excellent quantum centers in Gdańsk and Warsaw. The working group for the development of the Strategic Research Agenda of the SRA-WG also includes a representative of Poland, a professor currently working abroad. In the European Consortium of the Quantum Industry [6] affiliated to the EQF, the Polish excellent company Creotech is a member of the SME group. There are no representatives of Poland among the authors of official EQF documents. One can ask the question whether the presence of intellect and innovative resources from Poland is sufficient for such a great initiative?

The European EQF Initiative is an action launched in parallel with a similar legal action at the level of the US Congress, approving the 10-year National Quantum Initiative Act NQI and signed in December 2018. The NQI has an NQCO coordinating office located in the OSTP White House Office of Science and Technology Policy. NQI is a kind of umbrella over the activities of such agencies as NIST, NSF, DOE. As part of these activities, the QED-C Quantum Economic Development Consortium was created, composed of industrial, academic and government institutions. NQI publishes open documents on the progress of work in individual thematic sectors of quantum technologies and data on finances supporting such current activities in the QIT sector. The analysis of these documents shows how serious this initiative is in terms of the massiveness of research, economic, political and economic activities, as well as social ones. This is not the first of such massive technological initiatives in the USA. Other examples can be cited, like the National Photonics Initiative NPI launched a decade ago and still actively implemented. Similarly, massive actions in the QIT sector are being undertaken in China. The European QIT initiatives, including the EQF discussed here, are joining the much wider global QIT development effort.

V. European Research Strategy and Industrial Agenda in QIT

The Strategic Reaseach and Industry Agenda [7] published by the EQF in November 2022 is a document resulting from the EQF research and development activities to date, supplemented by an industrial road map, and numerous other European initiatives in the area of QIT implemented by individual countries and European agencies and international organizations. The development of the document was coordinated by the CNRS in Paris. Currently, it is the most complete source presenting the panorama of QIT development in the widest sense in Europe in the time horizon until 2030. Despite its very rich content, this document is modestly referred to in the introduction as a preliminary step to develop a scientific and industrial European agenda and a quantum road map. Grouped in the EQF, the authors, editors and publishers of this collective study have a clear respect for the enormity of our ignorance regarding the potential possibilities of quantum technologies and their transformation into functional systems. On the other hand, however, the knowledge they already possess entitles them to make bold and practical recommendations. The document shows this uncertainty in the form of a breakdown of such recommendations into short-term two-year, medium-term five-year and long-term until the end of the decade and beyond. In other words, EQF-SRIA is a carefully selected list of European quantum ambitions that, under certain assumptions, have a chance of being implemented within a decade, divided into shorter time steps. These chances for building the foundations of quantum civilization do not depend only on Europe, but also on other world centers, some of which are more advanced in certain areas of innovation and implementation.

The political and economic context can be read between the lines in the European quantum research and industrial strategy EQF-SRIA. The style of presenting the material of the quantum agenda clearly shows the strong influence of the standardized European science policy on roadmap development schemes also in other areas of science and technology. In this sense, the document can be treated as more scientific-political than scientific-technical. However, this forward-looking "political" layer is based on strict scientific premises and current views on the development of quantum technologies in different time horizons. The entire analysis is coordinated to the four pillars of quantum technologies - computing, simulation, communication as well as sensors and metrology, and interactions between them. Understanding precisely the existence of a non-trivial interface between the worlds of science and innovation and industry, the EQF-SRIA document is a methodological composition of two strategies - the research EQF SRA - Strategic Research Agenda and the industrial EQF SIR - Strategic Industry Roadmap. This submission is made against the background of other significant European initiatives in QIT and related areas. The SRA represents an integrated European science vision for QIT. The SIR, developed by QuIC - European Quantum Industries Consortium, represents the vision of the European industrial environment. The EQF-SRIA strategy takes into account the strategic plans of other key initiatives, such as the EU EuroQCI Declaration signed in June 2019 - on the construction of the European Quantum Communications Infrastructure, the EU EuroQCS initiative - on the construction of the European Quantum Computing and Simulation Infrastructure, EuroHPC JU - European common project in the field of high-performance computing, and the European Chips Act - an Act of the European Parliament on securing supplies of semiconductors to Europe (under preparation).

The document also indirectly reflects a certain concern about the extremely strong competition from the US, and especially from China. It is worth giving an example that IBM plans only one task in 2023 - the launch of the 1000 qubit CONDOR processor and the opening of a new line of Heron, Flamingo and Kookaburra processors starting the development path to 4000 qubit and larger systems planned by 2025. The Chinese company has started selling a compact a relatively cheap quantum computer. Will Europe cope with these challenges? Scientifically yes, but also on an innovative and strictly functional industrial levels? Such a developed quantum infrastructure, commercially available, also partly made available to the public via IBM Quantum, is currently not available to any other company [8]. China follows a different path, where significant funds, over 100 MEuro per year, are invested in the vast majority by the government in the development of quantum networks. Probably no one else has such an extensive quantum network. In the US, quantum funding is spread across multiple research funding agencies, universities and private companies.

The global EQF-SRIA document should also look to some extent beyond current trends in order to anticipate the unexpected. In a sense, such an approach to QIT can be found in an attempt to look beyond 2030, and even to 2050. The distant goals of building a civilizational QIT infrastructure have been generally defined, but are strongly based on the classical foundation. This year 2050 is repeated in many strategic European, but also American and other documents concerning the development of science and economy, and generally the economic and technological background of civilization. One can cite an example of the development of energy in Europe in the time horizon of 2050, in which there is room for the DEMO fusion experiment, which is the successor to ITER. A completely different, but adequate example is the excellent document of the influential global organization IEEE Advancing Technology for Humanity "IEEE in 2050 and Beyond", showing four scenarios of the socio-technological development of civilization. In the case of QIT and its classical counterpart ICT, for these far-reaching plans we have commonly used trivial terms like computer and quantum network. Although, as we vaguely predict today, neither a computer nor a quantum network will resemble those devices and systems that we now call a computer and an ICT network.

Somehow these efforts and their goals need to be named today, and only time will create appropriate names for them in the future. A characteristic feature of these terminological assignments is the use of terms analogous to ICT in relation to the new QIT area. And so, in the ICT, physical and energy resources are current, voltage, and the manner and inertia in response to the change of these resources. Information resources are, for example, the available processing power of the processor, memory resources, latency, system clock and allowed calculation time. In QIT, the information resources are entanglement and contextuality as well as decoherence time. In detail, for example, the method of transforming the physical quantum layer into the logical layer, the channels of quantum coupling with the thermodynamic world, i.e. the degree of openness of the quantum system and, therefore, its susceptibility to quantum errors. Physical resources may be, depending on the QIT system technology, e.g. the number of effectively deterministically available single photons with appropriate properties. The control is carried out by optical and microwave signals. These differences in resources run deep and make quantum systems completely different.

In the quantum strategy of the European EQF-SRIA, more important than only partially foreseeable distant future, is tomorrow's future, a few years away, and at most by the end of decade, giving socially useful products. Usability is best perceived in areas such as health, safety, communication, etc. It is also about products that familiarize society with new technologies and create a favorable atmosphere for economic activities in the area of QIT. The EQF-SRIA is formatted in this way. It is about identifying as precisely as possible specific projects that should be undertaken not only within the EQF but globally on an European scale in order to functionalize quantum technologies. These activities are coordinated by the scientific and industrial foundations and the four pillars set on them, indicating the directions of quantum technological development: computing, simulations, communication, sensors and metrology. The presented analyzes also concern scientific and technological cross-sections in relation to the mentioned pillars. Such an orthogonal view of the technological quantum directions now taken for granted, perhaps allows to slightly reduce the probability of making a larger error of analysis or omitting something important, hidden in the correlations between the pillars rather than in the pillars themselves. Such a cross-section of quantum pillars is also a method of searching for their potential common denominators. We are now almost certain that this common denominator may be quantum resources. However, the nature of quantum resources is known only superficially. Mastering the methods of managing quantum resources in these pillars requires further extensive research. Cross sections, from an innovation and industrial perspective, include education and skills, human resources, standardization, intellectual property and trade management policies, and more.

VI. European Quantum Roadmap for a Decade

Building a European quantum computing and simulation community includes activities ensuring access to technologies produced in industry, academic laboratories, innovative companies and start-ups. The EQF project enables the purchase of quantum products and services and acts as a platform for collaboration between users and manufacturers of hardware and software. European and national HPC centers will be equipped with quantum computing nodes enabling cooperation between them. Supporting the creation of the European QIT environment is a multi-component process in which the EQF plays a number of roles such as initiator, integrator, amplifier, etc. The demonstration of practical strategies for the evolution from NISQ to FTQC strongly reinforces the building of the environment. There are many such components that strengthen the implementation of the quantum strategy in Europe: activation of semiconductor manufacturers in the quantum direction, stimulation of the fields that make up the technological and IT environment of QIT, such as science and materials engineering, efficient cryotechnologies, development of HPC centers with a quantum component, standardization of the QIT area, supporting technological laboratories, etc. The area of quantum simulations and annealing is in a way complementary to gated quantum computing. The difference lies in the construction of specialized quantum processors that enable operation in the area of applications that potentially solve problems that are impossible to handle in classical computers and in gate quantum computers. European quantum science and technology, according to EQF-SRIA, should develop all three different classes of quantum computers – logical gates, simulators and annealers. It is also important to develop, in addition to digital techniques, quantum analog techniques.

The goal of quantum communication is to develop tools and protocols for exchanging quantum information between remote users. The QIT covers the classical and quantum layers, and within the quantum one, hardware and software. Currently, the QKD quantum key distribution stage is being developed, as well as similar simplified technologies rather related to quantum local transmission. The target stage is the construction of a quantum network with functionalities resembling the current Internet in the future, but currently of a complementary nature, extending rather than replacing the classical network. Three main directions of development related to the improvement of network parameters, integration and industrialization are envisaged, i.e.: increasing the speed and distance of transmission, and environmental resistance of all types of quantum telecommunications, optimal combination of classical and quantum telecommunications in the areas of infrastructure and applications, industrial implementation of quantum ICT infrastructure cost-effective economically and socially.

Current quantum ICT applications are related to cryptography and cybersecurity. Quantum computers pose a potential threat to classical cryptography. Two alternative ways of securing computing and transmission systems are considered in the era of FTQC, or even later universal quantum computers, rather than NISQ. These are the QKD quantum key distribution and post-quantum cryptography being developed in parallel. Post-quantum cryptography, referred to as PQC, is related to the development of algorithms, currently generally of the public key type, which potentially provide security against all types of cryptanalytic attacks performed with the help of the QIT.

The European Quantum Strategy lists the key components that require an urgent intensification of development in order to increase the functionality of the early stages of development towards the quantum Internet. These components are mentioned in all published scientific, economic and political documents concerning the ICT sector, American, Chinese, Japanese, British, etc. There is therefore a large consensus of views in this regard on a global scale. Quantum repeaters will allow for the connection of many users over considerable distances through quantum channels that maintain, do not distort, and in the long run distill quantum signal resources. Most often, these will be quantum optical fiber channels generating and maintaining the state of quantum entanglement of distant users. For very long distances, it is necessary to develop, in addition to a fiber optic network, a satellite quantum backbone network. The terminal nodes of the hybrid classical-quantum network, in the personal layer, will be stationary and increasingly mobile computers and smartphones of users. Of course, there will also be an extensive M2M layer. User devices must be adapted to use the new type of hybrid network functionality. Today, it is still difficult to imagine quantum analogues of laptops and smartphones. We rather think about development environments and services for using quantum functionalities in the cloud. However, such a solution, certainly adapted initially, does not fully create a quantum closed system.

VII. Conclusions

The Quantum 2 area of the QIT is a challenge of mastering the techniques of precise manipulation of a single atom, a single electron and a single photon. So far, we have mastered such skills only very superficially. And the future quantum Internet is strictly the Quantum 2 area, built on the previous good foundation of the Quantum 1 technology. Europe, Poland, and we all together are diligently trying to functionalize quanta and qubits to the QIT products and services.

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