Position Paper

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Priorities for Horizon Europe's Digital, Industry and Space Cluster

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The Guild
of European Research-Intensive Universities

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Introduction

Since the 1960s, digital technologies have seen enormous advances, which have been propelled by enhanced computing power and the parallel decrease in costs. According to the OECD, "today, an ecosystem of interdependent technologies generates digital transformation and will evolve to drive future economic and societal changes."[1]

Digitalisation is radically changing our societies as well as business processes and industries. But while digital technologies offer enormous opportunities, they also pose important societal questions related to, for example, their rapidly growing energy consumption (already standing at 7% of the world electricity consumption[2]), their inclusiveness and their role in addressing pressing challenges such as climate change. At the same time, space science and technologies are key drivers towards achieving the UN Sustainable Development Goals (SDGs). As examples, space-based services and technologies can enhance resilience against natural disasters, help monitor water and air quality, and contribute to sustainable agriculture and the monitoring of food production and security.

To benefit our societies, research into new technologies and industrial processes needs to be coupled with value-driven research, to achieve a better and more sustainable future for all. Cross-sectorial and interdisciplinary collaborations will be of paramount importance in this respect, while the combination of fundamental and applied science is the way forward if Europe aspires to become a global leader in these domains.

This document presents priority areas for Horizon Europe's Digital, Industry and Space cluster stemming from The Guild's academic community. As this cluster covers a variety of areas of intervention, our input focuses on those that offer the highest potential in tackling global challenges.

1. Artificial Intelligence

Artificial Intelligence (AI) is rapidly gaining importance in daily life and becoming a key competitive advantage for the private sector. In addition, it could revolutionise the public sector. However, Europe currently invests less in Artificial Intelligence

[1] OECD (2019), *Going Digital: Shaping Policies, Improving Lives*. OECD Publishing, Paris, p. 18. Retrieved from https://doi.org/10.1787/9789264312012-en.

[2] Lannoo, B. (2013), *Energy Consumption of ICT Networks.* TREND Final Workshop Brussels. Retrieved from https://bit.ly/2N0H6L6.

than the US and China.[3] A collective and decisive EU research and innovation agenda for AI is essential to guarantee that the benefits of AI will reach all European citizens and businesses.

The main challenge for the next decade is to develop methodologies for solution-oriented, trustworthy AI. With a human-centred focus on AI, Europe can make a difference and compete with the US and China, while staying committed to Europe's core values. Important issues, with corresponding challenges, include:

- *Reliability and safety*: building AI systems that operate within predefined operating constraints;
- *Data privacy*: learning from large amounts of personal data without infringing the privacy of citizens;
- *Fairness*: mitigating bias in training data;
- *Liability*: making AI systems transparent and designing a legal framework around AI;
- *Usability*: improving the interaction of AI systems with humans;
- *Inclusiveness*: designing AI systems that benefit all people, not just the happy few, and learning how to engage the general public in the development and use of AI.

Expected impact

When successful, AI can have a huge impact on society and industry through increased process efficiency, better predictions, and more personalised solutions. AI is likely to become the main enabling technology in the following decades across a wide range of fields, like transport and logistics, smart industry, healthcare, and education.

Key R&I orientations

Many AI issues clearly benefit from input from various disciplines, but are at their core still technological challenges that require technological solutions. Europe has to invest in the development of these solutions and avoid becoming too reliant on those provided by others. New research should be inspired by the needs of citizens, leading to a mix of basic and applied research in industry-academia partnerships.

Progress in AI will derive from more accurate algorithms, supported by specialised hardware solutions, that make AI systems explainable, fair, scalable to huge volumes of data, able to tackle a wider range of problems and transfer knowledge from one task to another, adaptive in dynamic environments, and increasingly context-sensitive.

2. Advanced computing

It is widely recognised that reducing the energy consumption of computing will be essential to sustain growing digitisation in our societies, to support industry towards higher efficiency and economic growth, and to make this technology more accessible. So far, this has been pursued mainly by stimulating research on relevant hardware-related aspects, such as new generations of materials and of low-power processors. This is only the beginning of a more comprehensive and system-oriented approach where energy efficiency comes from the synergy of systems, networks and computing layers, which call for novel basic research methodologies as well as for disruptive technologies. From this perspective, the main challenges that Horizon Europe should address are:

- Reducing energy consumption in advanced computing via: (a) Hardware improvements (in terms of new materials, new circuit designs, new low power processors, etc.); (b) Operating systems improvements (e.g., energy-aware resource management); (c) Networking improvements (e.g., networking communication footprint and energy reduction via fog computing); and (d) Algorithm improvements (for big data classification, etc.);

[3] McKinsey & Company (2016). Artificial Intelligence Investment 2016. Retrieved from https://www.mckinsey.com/featured-insights/europe/ten-imperatives-for-europe-in-the-age-of-ai-and-automation.

- Facing the breakdown of Moore's law via alternative and disruptive computing approaches, such as quantum and neuromorphic computing, spintronics and photonics;
- Maintaining the EU's sovereignty in advanced computing via 'first-mover' leadership in energy reduction and alternative computing methodologies;
- Increasing the robustness and reliability of advanced computing solutions, both when they operate in isolation and as part of integrated ecosystems, to increase citizens' trust and sense of participation in an EU-centred sovereign ecosystem of data and computing resources.

Expected impact

Successfully addressing the above challenges will generate significant innovation impact for society and digitised industry in Europe, primarily by:

- Improving sustainability via the reduction of energy consumption (e.g., 30% less for fog-optimised communications in the distributed cloud continuum; reduction of energy use of orders of magnitude for neuromorphic computing);
- Introducing disruptive and more efficient alternative computing models, methodologies, systems, and algorithms. This will ensure EU leadership in non-traditional and 'risky' areas of basic research, such as neuromorphic computing;
- Increasing the autonomy and recognition of the EU as a trusted leader in advanced computing, e.g., applied to community-oriented big data management and processing;
- Increasing productivity via the improved quality of products and services (by achieving for example fault/defect reduction), as well as increasing citizens' satisfaction and trust in and societal acceptance of advanced computing ecosystems.

Key R&I orientations

To achieve the abovementioned goals, key collaborative R&I orientations should include:

- R&I actions that consider full-system-oriented approaches to energy reduction by addressing the different related aspects and layers (namely hardware, operating systems, networking, and algorithms);
- The development of basic research on new materials, models, methodologies, and algorithms for quantum and neuromorphic computing;
- Innovative business and citizens' involvement models for smoother and more efficient transitions from fundamental science to applied market-oriented solutions. These models should be able to stimulate the creation and growth of open, robust, reliable, and trusted ecosystems, capable of involving SMEs, local communities, and citizens.

Finally, it should be noted that the above challenges and R&I orientations call not only for significant basic and applied research, but also for expanding citizens' education and skills in the related research/industrial areas; this is needed for competitiveness in the EU. The synergies between Horizon Europe and other programmes such as Digital Europe are crucial enablers.

3. Manufacturing

European industry is facing challenges in remaining competitive while also meeting demands on sustainability and resource effectiveness. This requires not only new technologies, but also educating a new workforce knowledgeable in societal and value-driven innovation, thereby ensuring that technological advancement will correspond to societal needs and connect to sustainability goals.

The main challenges manufacturing technologies face include:

- *Additive manufacturing*: replacing cutting and welding may help reduce the material consumption of industry components by 50% by 2035. For this transformation to be achieved, fundamental research on new alloys and compounds along with innovation of precursor materials is needed, but also structural changes in components through new technology.

- *Productivity*: We need to improve process productivity in manufacturing through the combined exploitation of edge cloud computing, machine learning, industrial and interoperable Internet of Things (IoT), and distributed big data processing. A goal would be an increase of productivity by 25%. One of the ways to achieve this goal may be technology driven, enabled by Artificial Intelligence, but much will have to be obtained by fast and distributed innovation on-site.
- *Latency*: Robots and collaborative guided vehicles can be used to decrease latency in manufacturing and in smart cities by up to 500%. 6G communication tools and edge computing are the enablers of this technology.
- *Recycling*: Life cycle analysis and recycling require the identification of the materials used for each product and component (i.e., type of material, provenance and how components are assembled). This needs intelligent product design. The challenge is to manufacture durable goods, containing components that can be replaced and recycled easily. Feedback from stakeholders is crucial in this iterative process.
- *Energy efficiency and waste reduction*: Energy efficiency and CO2 reduction is needed, e.g., in steel production (replacing carbon-based fuels with hydrogen) and in the cement industry. In addition, renewable electric power production on-site will reduce net consumption from manufacturing. A combined challenge would be to obtain zero-defect and zero-waste manufacturing plants, where waste during production is decreased, all materials are recycled, and the amount of energy used is minimised. Products should be sustainable, traceable, high-end, have a long lifetime and competitive pricing.

Expected impact

The role of universities in fundamental science is paramount to successful innovation in disciplines such as physics, engineering, IT technology and the social sciences. Industry will benefit from new open data models, open science and open innovation. A goal would be to develop software technologies for distributed virtualised resources, distributed machine learning, etc., capable of building shared ecosystems of algorithms, tools, and datasets and of democratising ICT access for SMEs and the whole of society.

Key R&I orientations

Some of the key components for a zero-waste fully automated manufacturing plant include an efficient interaction between humans and computer systems, high-speed computers, and sensor systems. Given the objectives related to sustainability and societal needs, key topics for collaboration would be in the areas of intelligent laser systems, high-tech plasma systems for material shaping and thin film production and surface modification, and water-based hydraulics to replace hazardous fluids. Artificial Intelligence and machine learning development includes research and innovation in distributed control systems and IoT, intelligent production management systems, self-diagnostics and smart sensors.

4. Advanced materials

Rapid progress in the fields of new energy sources (its conversion and reduction), organic electronics, information storage, and computing, is not only fuelled by purely technological improvements. It is also driven by scientific discoveries of new materials and methods. At the same time, we are witnessing a growing tendency towards the miniaturisation of devices used in everyday life (e.g., integrated circuits or optical information transfer technology, molecular electronics), which is attracting great interest in nanotechnology and nanoscience. New device concepts beyond conventional electronics such as spintronics and photonics will have to be integrated, while an understanding of nano tribology properties of new or improved sliding materials and its surfaces can significantly improve lower energy consumption.

As materials themselves, rare earths are essential components for the application of advanced materials. However, as they do not originate in Europe, it is extremely important to find new composites that could replace them in products such as permanent magnets and in electronic devices.

Another important challenge is linked to the development of eco-friendly materials for environmentally sensitive areas. Advances in the chemical synthesis and material sciences has opened countless possibilities for the design of new compounds, allowing also for tuning their properties in many ways. Thus, the understanding of processes leading to the controlled modification of electronic and structural properties of solid surfaces are of major importance.

Expected impact

The main expected impact in this area will be the implementation of new functional materials (including neuromorphic materials) into complementary metal-oxide-semiconductor (CMOS) technology. This will foster transformative progress in electronics and beyond.

Outcomes of R&I actions will also lead to an increased usage of new materials, nanotechnologies, and of eco-friendly materials, as well as to increased recycling. The combined impact of these advances will increase Europe's industrial competitiveness and enhance citizens' quality of life.

Key R&I orientations

To respond to these challenges, every study of new material should start with fundamental research on:

- Principles modelling (e.g., computer predicting models);
- Electronic and mechanic material properties via fundamental laboratory research;
- Integrating fundamental knowledge on new advanced materials into functional electronic, spintronic and photonic devices;
- Social contribution and interdisciplinary work that can help us understand how the use of new materials can contribute to the EU's strategic priorities and benefit our society.

R&I collaborations should cover the following specific areas:

- Fundamental materials research in view of new functionalities beyond conventional electronics (e.g., photonics and spintronics).
- Developing photonics and photonic materials for energy efficient data processing and transport.
- Searching for new photonic materials, components and systems engineered to achieve designed nonlinear photonic and nano-magnetic readout modalities to sense biological activity (e.g., implemented colour centres or defects in the crystalline diamond, with specific magnetic and optical properties).
- New expertise for spectroscopy, imaging and ultrafast science, benefitting from the unique combination of bio-nano-photomagnetic interactions.
- Research into new materials, in particular: (a) magnetic and electronic materials with a minimum quantity of rare earths; (b) Environmentally friendly materials for different applications (e.g. protective elements in electrical engineering and electronics); and (c) Functional coatings.
- Research into nanotechnologies: (a) Smart nano bio/chemo sensors; (b) Smart coatings and surfaces; and (c) Surface nanoparticles, boundary layers and surface nanotechnologies which replace bulk materials.
- PLD technology for pilot testing and industrial preparation of high-quality oxide thin layers.

5. Space

Space research is a critical asset in managing the environmental challenges that affect communities across the globe, such as hydrological extremes. Today we lack reliable and up-to-date climatological data in many regions worldwide, this is partly due to the decline of expensive ground-based monitoring infrastructures. This increases uncertainties in measuring aspects such water cycles and hinders the development of effective real-time monitoring and early warning systems, which ultimately negatively affect our ability to mitigate the risks associated with natural disasters.

Beyond the immediate benefits of space technology, managing how we deal with potential vulnerabilities, notably space debris, is another major challenge. Current models suggest that there are almost 130 million debris objects in space, ranging from just a few millimetres in size up to many meters (ESA, 2019). The potential damage caused by collisions might disrupt widely used satellite-based services (such as for GPS or satellite-based mobile communications), as well as the overall sustainability of the ecosystem surrounding our planet.

Space research also provides the opportunity to explore the planets and moons in the Solar System, which can become the greatest challenge of the 21st century. Comparative planetary science enables a better understanding of the processes that shape our own planet.

Other challenges in space research are related to monitoring space weather, and near-Earth asteroids and comets, which can pose a threat to our planet and our assets in space. Beyond the solar system, space research also allows us to explore the evolution of matter and energy in the cosmological framework, and to search for habitable planets around other stars.

Finally, harnessing the potential of 'Big Data' from space is another challenge that will require urgent action in the future. The landscape post 2025 will be characterised by a large number of new generation space facilities that will provide immense datasets, all with the need to interact and to be correlated with each other.

Expected impact

EU collaborations in the above fields are crucial to better predict and mitigate the impact of natural disasters. For example, gravity observations from space and from the ground will enable the precise detection of changes in the water balance and to quantify the water mass exchange between regions, continents and oceans on a global scale.

Collaborative R&I will reduce the risk of in-orbit collisions, thereby contributing to keeping space-based services optimal and well-functioning, while research in comparative planetary science will improve our understanding of the processes that shape our own planet and prepare us for future Solar System exploration.

Finally, R&I will help optimise analysis and contribute to new and existing synergies between different big datasets obtained from space and complementary ground-based facilities, thus advancing knowledge in several research fields from Earth-observation to Astronomy and Cosmology.

Key R&I orientations

To help address the effects of natural disasters, research is needed on how to add gravity data into existing operational Copernicus activities. The primary observation techniques of Copernicus' Next Generation of Sentinels (NGS) rely, so far, only on Microwave Imaging, Optical Imaging, Topographic and Spectroscopic Atmosphere Measurements. This excludes the observation of mass changes in the hydrological cycle. Only the combination of gravity missions and other satellite and modelling data will enable the quantification of all hydrological compartments including ground water, surface water or ice melting. Horizon Europe should therefore actively support the development of Next Generation Gravity Missions (NGGMs) – as a future Sentinel candidate – and the real data analysis of current gravity missions and simulation studies of future gravity missions.

In-orbit capture, servicing, and efficient de-orbiting of non-operational satellites will be key R&I orientations to diminish space debris. The full exploitation of big datasets required in space demands the development of IT infrastructures and computing methodologies, algorithms, mechanisms, tools, and distributed/federated cloud continuum-based solutions (for the efficient treatment and analysis of 'Big Data' coming from space: i.e., Earth observation and other bodies of the Solar System to Astrophysics and Cosmology).

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