

A black and white photograph of a seagull in flight against a cloudy sky, with a dark, rocky cliff face in the foreground.

FONDAZIONE
Links
PASSION FOR INNOVATION

LINKS FOUNDATION

Annual Report.

Report on operations and results

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**20
21**



Contents.

introduction	4	Letter from the Chair.
	6	2021: a year of structural transformation.
goals	10	Accelerating the Competitiveness (ACO).
	12	Accelerating the Common Good (ACG).
	15	Accelerating the Innovation Ecosystem (AIE).
CTO	18	2021 digital innovation trends and key results of LINKS research activities.
research domains	22	Advanced Computing, Photonics and Electromagnetics (CPE) <ul style="list-style-type: none"> • High-Performance Computing • Materials and Technologies for Photonics • Computational Electromagnetism and Special Antenna Design
	27	AI, Data & Space (ADS) <ul style="list-style-type: none"> • AI and Data Science • Space Applications • Managing emergencies
	30	Connected Systems & Cybersecurity (CSC) <ul style="list-style-type: none"> • Connected and Autonomous Mobility Systems • Cyber Physical Systems and Industrial IoT • Cybersecurity
	33	Future Cities & Communities (FCC) <ul style="list-style-type: none"> • Mobility and logistics • ICT for energy and people • Climate change, cities and the environment
	36	The Internet of Value and the Token Economy.
in-depth analyses	36	The Internet of Value and the Token Economy.
	39	Quantum Computing, the new frontier of HPC.

Letter from the Chair.

4

2021 was a year of major transformation for LINKS. In particular, the **new Constitution** approved by the members set out a clear statement of “who we are and where we are going”.

Art. 3 of the new Constitution warrants special attention:

“The Foundation’s purpose is applied research and technology transfer aimed at pursuing innovation and the digital transformation of society, through the widespread and pervasive use of digital technologies, in line with European Union guidelines for the digital metamorphosis of society and with a special focus on the development of and impact on the catchment area in terms of innovation”.

LINKS is therefore a research body, whose primary purpose is **research-based innovation** within a specific context. It also gives high priority to consolidating its position within international networks, especially in Europe. Not only because this is a significant source of funding, but also in view of the need for the international exchange that underpins the value of science and technology.

This is complemented by the need to play a key role in **digital transformation**. From the explosion of the internet in the late 1990s, to social media as a new paradigm of global communication and to the recent Metaverse, which is leading us towards a world where the real (material) and virtual are hard to distinguish, society is experiencing an exciting, and in some ways dramatic, revolution. Its importance is equal to, if not greater than, that of the industrial revolution between the 19th and 20th centuries, which has and will continue to have significant influences on society from an economic, social and, perhaps, ethical point of view. It is up to scientists and researchers – hence to us – to guide this rapid transition, and endeavour to secure the good and the future of humanity.

Our global vision of innovation and transformation, however, must not blind us to the **local context**. Our role as an agent of local development is clearly outlined in art. 3, and this requires us to pay particular attention to businesses and the world of production, with which we must strengthen our links and partnerships.

Fostering and extending our relations with small, medium and large enterprises is a high priority for LINKS, not only as a means of boosting our sustainability and capacity for self-funding – which is nonetheless a

necessary objective – but primarily to fulfil our role as a development accelerator, which is vitally important in the industrial transformation now under way. This is all the more important in our own geographical area, which has long been based on manufacturing linked with the automotive sector, which is now undergoing a period of profound change.

In this respect, it is worth citing point e) of article. 3 of our Constitution, which sets out the purposes of LINKS: **“to steer, coordinate and implement initiatives aimed at societal innovation within the lines of action of Compagnia di San Paolo and the Polytechnic University of Turin”**, while specifically indicating the role of LINKS in the innovation chain, which in recent years has translated into the acquisition of shares in i3P, 2i3T, Torino Wireless, the establishment of LIFTT and, as of 1 January 2022, control of ITHACA srl.

LINKS: not only an applied research and technology transfer body, but an auxiliary body of the Founder Members, tasked with overseeing the innovation chain.

President
 Marco Mezzalama




2021: a year of structural transformation.

6

No-one could have imagined that, after commenting on the dramatic effects of the pandemic in our 2020 annual report, our 2021 report would also open with a reminder of other tragic events, namely the war in Ukraine, which started on 24 February 2022, but which we cannot fail to mention in this annual report. It is a sign that “black swans” are unfortunately becoming an ordinary reality and that the Western world – and Europe in particular – is witnessing, often as a powerless spectator, a succession of dramatic events around the world, which started with the first Gulf War that broke out in January 1991.

Despite the continuing obstacles posed by the pandemic, 2021 can be defined as a year of structural transformation for Fondazione LINKS, in which important decisions were taken that will have a profound impact on the foundation's future development: a new **Constitution** was drawn up in May, and the first half of the year also saw the launch of the new **Strategic Plan 2021-2024**, which involved a major internal reorganization and has opened the doors to new guiding values, new goals and a new vision of LINKS.

Constitution

The new Constitution establishes the foundation's goals more specifically, and underscores its instrumental role in the ecosystem of Compagnia di San Paolo and the Polytechnic University of Turin. On the basis of this new Constitution (which increases the number of directors), the Chair, Marco Mezzalama, was re-elected in June 2021 and six other Directors were appointed, of whom two were members of the previous Board and three were independent (i.e. they were not staff members of Compagnia di San Paolo or the Polytechnic University of Turin).

Paola Bosso, Paolo Bonassi and Giovanni Tesoriere have joined the Board alongside its existing members, Marco Mezzalama and Stefano Corgnati, appointed by the Polytechnic, and Carla Ferrari and Maurizio Vanotti appointed by Compagnia di San Paolo.

The new Constitution also establishes a Scientific Committee and the possibility of welcoming Supporter Members who can bring skills, professional expertise and tangible and intangible assets with them, although the Board of Directors has not yet acted on these changes. It is worth emphasising that none of the above are just formal amendments designed to fulfil legal obligations: all are measures aimed ensuring that multiple actors from the social, economic and scientific world are more effectively represented within LINKS, while at the same time giving the foundation deeper roots in the scientific community and local area.

Strategic Plan 2021-2024

The plan identifies the need to support the foundation's research team with an organizational instrument capable of steering the scientific work to ensure that its results "land" among local stakeholders and that there is a high degree of listening and dialogue.

The plan, like the "Multi-Year Planning Document 2021-2024" of Compagnia di San Paolo, a founder member of LINKS, is shaped around the United Nations Sustainable Development Goals (SDGs) and EU policies. Its organizational model is also similar to that of Compagnia di San Paolo: LINKS's work is thus divided into various Goals and Technological Domains.

This has given rise to **three** organizational units known as **Goals**, which give the foundation's work a clear sense of direction. The aims of the Goals are to:

1. **Accelerate the competitiveness** of the business system, by bringing innovation into companies and improving the transfer of LINKS know-how.
2. **Accelerating the "Common Good"**, by generating innovation and impact in the public administration, the education system, the world of entrepreneurship and social impact investment, and the cultural sector. Through this Goal, LINKS institutionalizes its role as a research and innovation partner for the non-profit and public administration sectors, by means of the Social Tech and Culture Tech laboratories and the Italian National Recovery and Resilience Plan Observatory.
3. **Enrich the innovative ecosystem**, by fostering the emergence of new start-ups, increasing the number of HUB agreements and proactively managing the talent ecosystem.

The three Goals are backed up by **four Technological Domains**:

1. Advanced Computing, Photonics and Electromagnetics.
2. AI, Data and Space.
3. Connected Systems and Cybersecurity.
4. Future Cities and Communities.

The Technological Domains derive from the aggregation of some of the "Research Areas" that existed previously, but their value is more than just a question of organizational rationalization: in fact they were built on the basis of the principle of **hybridization between "technological competences"**, characterized by low Technology Readiness Level (TRL) and emerging developments that are still a long way from market readiness, and **"application domains"**, in which higher TRL values confirm that the developments in question are closer to market readiness.

First of all, applying the principle of hybridization has simplified the previous organizational structure, which was built on more than 15 "Research Areas". More importantly, however, it will enable personnel to be deployed more effectively in terms of cross-fertilization of skills, allocation of effort to projects and fostering a strong group spirit, thus marking a significant improvement over the management practices that had gradually established themselves over the years. Just a few months since its introduction, the new organizational structure is already showing a strong capacity to generate synergies and positive disruption, thus dispelling the few initial uncertainties that tend to be part and parcel of highly innovative schemes.

The Strategic Plan also explicitly indicates that Fondazione LINKS has a **"Strategic Marketing"** mission, is launching an **"ED-Tech 4.0"** mission to develop research programmes aimed at innovation in the educational arena, and is introducing a **system of proactive human resource management** designed to minimize skills obsolescence and take a structured approach to recruiting talented people who can be then kept on or – after a few years of field training – re-injected into the local enterprise fabric.

LIFTT and ITHACA srl

The new Constitution and the Plan also set out a role for the foundation as a **promoter of initiatives** aimed at the exploitation of the ecosystem's research and innovation activities by a variety of means, including the acquisition of shareholdings. In line with this principle, the foundation acquired shareholdings in the incubators i3P and 2i3T some years ago, subscribed to the capital increase in LIFTT in the first quarter of 2022, and

acquired all the shares in ITHACA srl with effect from January 2022.

Founder Members

2021 saw significant improvements and increases in **synergies with the Founder Members**. First of all, LINKS shared both the planning of the Constitution and the outlining, drafting and implementation of the Strategic Plan with the Members. More specifically, the **guidelines for writing the Strategic Plan** were sent to LINKS at the beginning of 2021. The plan was also aligned and re-read with Compagnia di San Paolo within the framework of the **"Policy-making and Coordination Committee"**, which involves all the Group's bodies.

In its **relations with the Polytechnic University of Turin**, LINKS acts increasingly as an auxiliary body for the University, as it does for Compagnia di San Paolo: in fact, the foundation participated in and contributed to the project aimed at strengthening the University Platforms in 2021. Furthermore, new scientific collaborations have recently been forged in addition to those already in place with the ICT departments (Department of Automatics and Information Technology [DAUIN] and Department of Electronics and Telecommunications [DET]): in particular, contacts have been established with the energy, infrastructure, urban planning and architecture sectors.

With regard to **Compagnia di San Paolo**, the foundation first of all shared the outline of the Plan with the Founder Member: in particular, LINKS comes under the umbrella of the **"Planet Goal"**, with which it shares numerous KPIs (about 40). In addition, the aforementioned ED-Tech 4.0 laboratory was created in 2021, in alignment with Compagnia di San Paolo.

Structural changes, both internal and in growth plans, have not put a brake on the development of **Fondazione LINKS's activities**. One of the most noteworthy initiatives is the assignment of the ESA BIC - Business Incubation Centre to Turin, within the framework of a project carried out by a grouping made up of i3P, the Polytechnic University of Turin and LINKS. The launch of the project entitled CTE Next - Casa delle Tecnologie Emergenti, in which LINKS is a participant, also warrants attention.

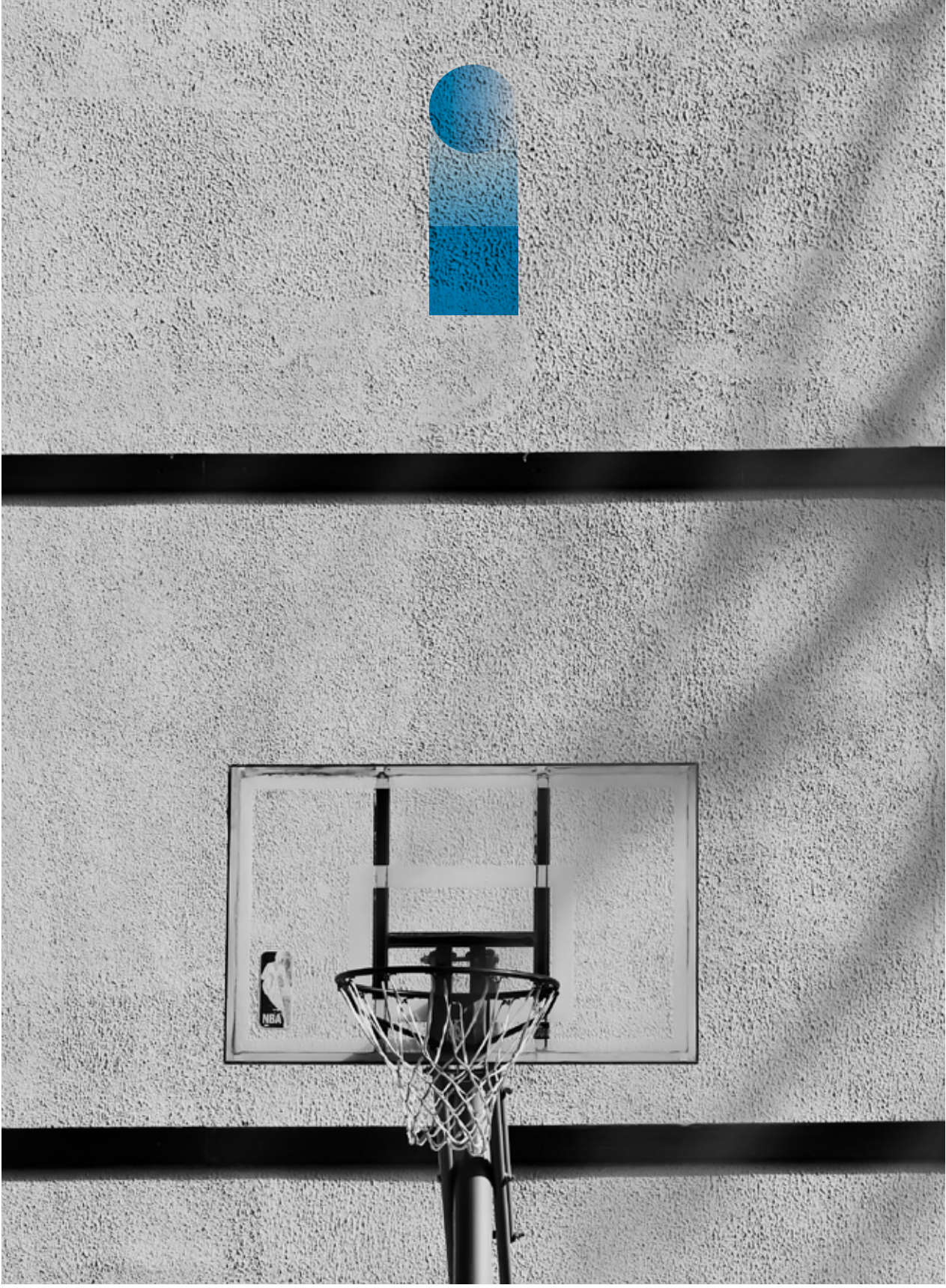
Many **collaboration agreements** have also been signed, including agreements with the Unione Industriali Torino (the Employers' Association of Turin) on the EIC Instrument, with Confindustria Cuneo and with Alessandria provincial council.

A large number of **projects were carried out** in 2021: these include the award of UNESCO World Heritage status to the Porticoes of Bologna, the 5G-IANA project designed to strengthen the 5G infrastructure, thereby enabling the development of key services for connected and autonomous cooperative mobility, the FET B-CRATOS project for the design of a bionic arm with innovative techniques of interaction between the brain and the mechanical limb, the Starlight and Appraise projects involving the value chain of Artificial Intelligence connected with security and law enforcement, the award of ESA calls for proposals under the Navisp programme, which will see LINKS working with SMEs from the space sector, the SEPROM project aimed at developing new electronic protection measures, IREN's energy community orders and new fibre optic projects developed with CISCO and SM Optics, and the interesting strategic analysis of the potential Carcare Predosa motorway infrastructure.

Having achieved good results from its projects and having strengthened its resilience through the structural changes made over the past year, LINKS will continue to extend its involvement and operations in the innovation ecosystem of Piedmont and North-West Italy in general. This is because there is no doubt that the urgent revival of the Turin economy and the transformations that new forces in international geo-politics will necessitate, will have to be built on a renewed commitment to innovation, and technological and knowledge transfer to the social and production sector.

Managing Director
Stefano **Buscaglia**



Accelerating competitiveness.

10

Certain skills and services of interest to all the Fondazione LINKS teams have been centralized in the Accelerating Competitiveness Goal (ACO), which thus takes on the task of proposing tools and methodologies, and identifying best practices relating to cross-cutting aspects of technology management, which remains the task of the four Technological Domains. In particular, ACO has been asked to develop proposals on how to organize and manage **Strategic Marketing**, **Technology Transfer** and **Joint Design**.

In fact, the three Missions entrusted to ACO share responsibility for the broader and more general task of exploiting research results, and therefore have numerous interactions with each other, as they work towards a common overall outcome.

Before reorganization, the activities covered by the three Missions were carried out by the individual Research Areas, but without any shared or formalized strategy. Although this approach still yielded positive results, it became clear that the work of the three Missions required more structured organization, in view of the size to which LINKS had grown, the complexity of the research topics it was covering and the recent drive to improve relations with the market.

First of all, a multifaceted proposal for the organization of the three Missions was drawn up in 2021, accompanied by efforts to identify activities in finer detail, which highlighted mutual dependencies and relationships. This resulted in the completion and internal evaluation of an organizational proposal in 2021, which includes activities such as:

- Recognising and organising – in partnership with the Technological Domains and the other Goals – the assets developed by the individual teams, and identifying which ones are best suited to exploitation (either through other funded projects or on the market). The advisability/necessity of encouraging LINKS as a whole to adopt project methodologies geared towards the exploitation and re-use of assets was also discussed at length.
- Identifying the **main stakeholders** of LINKS, classified by type. It was also proposed that an information system be created (or an existing system extended) for the purpose of storing this information and putting it at the disposal of colleagues who often need to identify end-users or partners for new project proposals.

- Identifying **best practices** for the exploitation of prototype ICT solutions, by drawing on the extensive experience that LINKS has acquired as a result of taking part in funded projects and commissioned research projects.
- Collecting semi-finished products, document templates and examples of methodologies deriving from successful projects.
- Drawing up a draft patent regulation, which plays an important part in the organization of Technology Transfer.

In order to fulfil the general mission of acting as a reference point and support team for the Goals and Technological Domains in their operations, in the closing months of 2021 certain members of the ACO team helped their colleagues draft parts of project proposals relating to the identification and description of assets, and the associated exploitation activities to be put in place. In some cases they also supported work on the same topics in projects already acquired by LINKS for which there was a shortage of skills and resources.

An event that impacted on all the activities of LINKS's research teams in 2021 was the launch of the new Horizon Europe (HE) programme, which, like the launch of previous programmes, introduced certain changes to the requirements, criteria and procedures for preparing project proposals. Training and briefing sessions on the new programme were held in 2021 and various actions were completed in response to new requirements imposed by Horizon Europe for eligibility to take part in funding opportunities, such as drawing up an initial version of the Gender Equality Plan (GEP).

In order to tackle the tasks assigned to it with due professionalism, ACO needs to strengthen certain skills. ACO therefore did some reconnaissance to identify appropriate specific training opportunities. These opportunities, relating to the Strategic Marketing sector, for example, will be put into practice in 2022 when the organizational framework of the corresponding activities is consolidated.

Accelerating the **Common Good**.

12

The Accelerating the Common Good Goal (ACG) originates from the aggregation of the numerous competencies that Fondazione LINKS has acquired over the years in managing interactions with the Public Administration (PA) and in designing services dedicated to one of the foundation's main stakeholders.

The ACG team is staffed both by Domain experts, who help public bodies prepare and draft applications for **UNESCO** awards, and technology experts, who have proved, over the years, to be especially effective in helping harness the value of cultural heritage, through the use of technologies such as **virtual reality and augmented reality**.

In terms of harnessing the value of cultural heritage on a non-technological basis, a number of successes were achieved in 2021 from the collaboration with public bodies interested in applying for UNESCO recognition for heritage assets located on their territory: the biggest success was securing a place for the **Porticoes of Bologna** on the UNESCO World Heritage List. The experience gained from working on these applications is also of interest to LINKS from the point of view of further opportunities for collaboration with the proposing bodies: in order to gain UNESCO recognition for a heritage asset, the proposing body must commit to carrying out projects to conserve/enhance the asset, for which the foundation can provide methodological, planning or even technological support.

In 2021, Fondazione LINKS took part in preparing the application for **Civita di Bagnoregio**, while also helping plan the conservation and enhancement initiatives for the site. Other projects carried out in 2021 include the revision and updating of the UNESCO Management Plans for Crespi d'Adda and the Longobards in Italy: Places of Power sites.

LINKS also worked on post-application initiatives relating to the **Vineyard Landscape of Piedmont: Langhe-Roero and Monferrato** project, and is planning to do likewise for the Porticoes of Bologna: more specifically, plans are in the pipeline for a crowdsourcing project aimed at collecting reports of graffiti of historical interest, to which LINKS could contribute its skills in the field of image recognition and processing.

Another major contribution that LINKS offers in this area takes the form of training and information activities on lesser-known types of UNESCO recognition: activities of this type were commissioned in 2021, and are

expected to continue in 2022.

The ACG Goal has also focused on **well-being**, which is central to the United Nations Agenda 2030, through research on well-being and initiatives to promote the adoption of healthy and sustainable lifestyles and practices designed to foster inclusion.

Projects have been carried out with a focus on the following:

- territory-specific forms of welfare, as a model of subsidiarity aimed at testing and adopting services designed to raise awareness of health and healthy lifestyles and improving occupational well-being, with a particular emphasis on technological tools and sustainable behaviours of workers. These themes were the focal point of the WE WIN Together project, co-funded by Piedmont Regional Council, with ESF and ERDF funds;
- sport as a vehicle for local development and social inclusion. The European STAR project contributed to a deep-dive into this theme;
- sustainability, as part of the drafting of a preliminary plan for the sustainability report for LINKS, aimed at enhancing the well-being of personnel, cultivating and stimulating environmental responsibility and collaborating with local actors to bring added value to the local context.

LINKS also drew up a **preliminary document for the sustainability report** in 2021, with the intention of setting out the initiatives that the foundation launched in 2021 – and intends to pursue in the future – in relation to sustainability and well-being, thus laying the foundations for a form of non-financial reporting designed to highlight the social and environmental value generated. These actions are inspired and shaped by the approach to sustainable development outlined in the UN Sustainable Development Goals (SDGs), the Global Reporting Initiative (GRI) standards, and the guidance provided by the Founder Members, Compagnia di San Paolo and the Polytechnic University of Turin.

LINKS intends to use this document as a means of reflecting on its impact on the local area, while planning and focusing its work with the aims of:

- enhancing the physical and psychological well-being of internal personnel;
- cultivating and stimulating environmental responsibility, by minimising its own environmental footprint;
- nourishing the local area by adding value to the context in which it operates.

In order to outline the action needed to achieve the aims described above, a process of involvement of internal personnel was implemented, in particular through experimentation, under the **WE WIN Together project** co-funded by Piedmont Regional Council with ESF and ERDF funds. The project included a thorough initial analysis of needs and the implementation of services within the framework of training on health, well-being, sustainability, disability, care management and coaching. A participatory process involving employees was also put in place. Through a cycle of meetings on sustainability, this highlighted certain reflections on environmental impact and the action that LINKS could take to minimize its own environmental footprint.

Taking account of the impact statements and the needs that emerged in the stakeholder engagement process, a number of initiatives were designed, which help achieve the impact targets. Some of these were partially tested in 2021 and could continue in the future, such as training/information on welfare and sustainability, measures aimed at maintaining a healthy work-life balance, the design of spaces for sustainability, interaction and socialization in the workplace and corporate voluntary activities.

Other initiatives, such as promoting sustainable mobility and workshops for repairing and regenerating electronic goods, could be put into practice as from 2022, including by setting up an internal think-tank. Metrics were established for each initiative and the results of the activities partially tested in 2021 were described.

As previously mentioned, for many years LINKS has worked with the **Public Administration**, trade associations and other bodies that can reap significant benefits from support for the projects and initiatives aimed at the design and adoption of digital services. Regulations and operating procedures for access to the substantial resources made available under Italy's National Recovery and Resilience Plan were drawn up in 2021: in

particular, the foundation set up a dedicated in-house Observatory, which six experts and researchers take part in. Established for the purpose of providing support mainly to colleagues in the Goals and Technological Domains, the Observatory also interacts with external actors such as members, local bodies and other stakeholders of LINKS.

The oversight and investigation activities have focused mainly on Mission 4 - Component 2 (which includes, for example, opportunities associated with the engagement of National Centres) and Mission 1 - Component 3 (relating to cultural heritage).

The work that started in 2020 with the Turin Chamber of Commerce and Confcommercio (aimed at the Borgo San Paolo district) extended its range of impact in 2021 with a different project on the Commercial district, undertaken in conjunction with ASCOM and Confesercenti, with the participation of Turin City Council.

Lastly, the ACG Goal – in partnership with IRES Piemonte – provided support in 2021 for the drafting of the Metropolitan City of Turin's Sustainability Agenda and the Regional Development Agenda on sustainability for the public bodies concerned (mainly from an environmental point of view).

With regard to our more technology-oriented work with public sector and cultural heritage partners, LINKS hosted several events connected with the **INVENTA project**, funded by the European Space Agency (ESA), in 2021.

1. The first of these was aimed at demonstrating a virtual group tour service, for the first time in Piedmont: a guide from Fondazione Musei led a group of visitors – connected remotely and equipped with virtual reality devices – on a tour of the virtual reconstruction of Palazzo Madama.
2. The second event was about neuroscience and neuro-rehabilitation and was organized in partnership with the CTO and "Città Della Salute": it involved a demonstration of the effectiveness of virtual reality in making the world of cultural heritage accessible to people who, for health reasons, are unable to physically visit the sites of interest.

Other projects, such as **VR4CBRN2** and **VERTIGO**, on which much work was done in 2021, relate to topics such as the delivery of training programmes based on VR techniques that "replicate" complex conditions (as in the case of deployments to accident sites).

Lastly, for the third year running, our foundation was elected as a member of the **European Science & Technology Advisory Group (E-STAG)** in 2021, by virtue of the ACG Goal's expertise in cultural heritage and the assessment of environmental impact and the impact of climate change. Supervised by the United Nations (more specifically the United Nations Office for Disaster Risk Reduction [UNDRR]), E-STAG supports the efforts of EU Member States to strengthen their strategies for preventing and mitigating risks from natural disasters and climate change. Our support played an especially important role in highlighting and dealing with the need to conserve cultural heritage.

Accelerating the Innovation Ecosystem.

2021

The Accelerating the Innovation Ecosystem Goal (AIE) has been asked to position LINKS as a technology facilitator and a generator of ideas, vision and talent at the service of local players, by facilitating development and stimulating dynamism within the innovation ecosystem.

15

Creating a real-world link between innovative technologies and the socio-economic context of a geographical area requires a multidisciplinary approach, similar to the one taken by the Accelerating Competitiveness Goal.

In 2021, the Goal started work on forging this type of connection by acting as an **"ecosystem builder"**, while also supporting LINKS in its new role as a holding entity, in the capacity of which our foundation has recently acquired shareholdings in entities and companies that are instrumental to the development of the innovation ecosystem and the action of its Members.

Two Missions have been assigned to the Accelerating the Innovation Ecosystem Goal.

Open Innovation Platform and Start-up Support Mission

The Mission promotes a collaborative approach through international agreements, support for the creation of innovative start-ups, and partnerships with universities, research centres and incubators to generate innovation in specific sectors. In 2021, the AIE team was involved in projects relating to Open Innovation and supporting and guiding the growth of start-ups and deep-tech spin-offs. The group's experience facilitates the development and consolidation of these highly innovative entrepreneurial activities through dedicated consultancy for the creation of business plans and the entrepreneurial exploitation of high-tech products and applications.

These activities are carried out in close collaboration with key players from the innovation ecosystem in which LINKS operates. First and foremost, these include the incubators of the University and the Polytechnic University of Turin and the Unione Industriali Torino (Employers' Association of Turin). An implementation agreement was signed with the latter at the end of 2021 in relation to the **InnovEIC programme**, the aim of which is to provide innovative local start-ups and SMEs with guidance on the European Innovation Council - EIC Accelerator funding measure. Throughout 2022, the AIE team will be providing support for companies interested in proposing scaling-up projects.

Annual Report 2021 AIE Goal

One of the Goal's tasks is to foster relations with key players in Turin's and Italy's innovation ecosystem, while monitoring the evolution of technological and market trends. As part of the multi-year partnership with the Intesa Sanpaolo Innovation Centre, the AIE Goal has worked on the production of numerous analyses of mega-trends (market, consumption, investment), innovation trends relating to specific industrial sectors and technologies, and scouting for high-potential start-ups.

In 2021, the team coordinated the production and drafting of the **Innovation Trend Report 2021 "People and Technology"**, designed to provide in-depth analysis of the development and upskilling of human capital and the contribution of technology to human resource management, new organizational models and organizational well-being within enterprises.

The AIE Goal also worked on the **2022 Innovation Trend Report on Aerospace**, to provide an overview of aerospace technologies, the offering of Italy's aerospace ecosystem and its potential impact on other sectors of industry. The report will be finalized and published by the end of the first half of 2022.

In conjunction with the CTO, the Accelerating Competitiveness Goal and LINKS's researchers, the AIE Goal has also facilitated subject-specific meetings with high-profile managers from the international world of technology, innovation and business.

Talent Mission

The second Mission was established to manage the talents who join the foundation, from the very first step of their journey. This approach, which puts personnel centre stage and sees them as a valuable asset, is also aimed at people who have worked with LINKS for longer. The starting point is to think of the local innovation ecosystem as a constantly evolving organism that needs a steady inflow of new professionals and updated skills.

In the course of 2021, the AIE Goal worked on the design of a structured pathway for the attraction, upskilling and retention of researchers at LINKS and within the local ecosystem in general, which will be launched in 2022. The actions planned or fine-tuned in the early months of 2021 also involved the University of Turin and the Polytechnic of University of Turin, as well as local companies and public bodies, with which joint workshops will be formulated in 2022.



2021 digital innovation trends and key results of LINKS research programmes.

18

As is now customary, major developments in digital technologies have been made over the past 12 months, despite the slowdowns caused by the pandemic, which had a significant impact on activities of all kinds (especially experimental ones) in both 2020 and 2021.

Some of the outstanding scientific and technological results achieved by the LINKS research teams have already been mentioned in the introduction. In addition to these, there has been a similar number of equally noteworthy cases in which our foundation has successfully guided companies and industrial partners through the process of digital transition, which now forms part of the roadmap of almost all businesses.

The **key drivers** of digital innovation, which have therefore also influenced the studies and projects carried out by our foundation, include the following:

Connected objects

Growing uptake of networked objects and Internet of Things architectures in general: the number of objects connected to the worldwide web continued to rise in 2021, reaching a figure of over 12 billion. This contributed to a significant increase in internet traffic and – as a direct result – an increase in demand for high-performance systems for data transport (including hard-wired and wireless peripheral networks and fibre optic backbones) and data processing (as the Continuum Computing paradigm described in the “Advanced Computing, Photonics and Electromagnetics” section gains currency).

Self-Driving Vehicles

Progress in self-driving vehicle technologies and the simultaneous spread of electric vehicles have forced public and private mobility planners to rethink systems and infrastructures in order to accommodate new types of vehicles, with new technological requirements (connectivity, network and processing system architectures, charging networks) and new regulatory requirements.

Space and satellite technologies

Space and satellite technologies are playing an increasingly important role in internet communications and earth observation, including for the mass market: the design and launch of satellites for the provision of innovative services, which have historically been the preserve of major companies and government agencies,

have reached a level of maturity that makes them accessible to start-ups and private companies. Initiatives such as Starlink, the SpaceX project that came on-stream in 2021 and is set to increase its reach in the years to come, pose new challenges from the point of view - for example - of the design of signal reception antennas, which need to be able to “track” satellites that are no longer in geostationary orbit.

Earth observation

The availability of increasingly extensive and accurate earth observation databases, such as the data sets provided by the Copernicus project (ESA), makes a valuable contribution to the construction of value-added services that even newly formed companies can design and bring to the market

Adoption of Distributed Ledger Technologies

Exponential growth in the adoption of Distributed Ledger Technologies (DLT) that underpin the Internet of Value. The evolution towards Web 3.0 started to take tangible shape in 2021, giving rise to numerous trials of innovative management and governance systems (of companies or other public or private communities) based on participatory and equity-driven socio-economic paradigms.

Digital twin paradigm

The availability of increasingly high-performance processing systems and telecommunications networks has facilitated the spread of special simulation and co-simulation systems that converge towards the digital twin paradigm, involving the creation of digital twins of physical object and systems. By combining simulation/emulation capability (which is now possible in real time) with a digital connection to the represented object, it is possible to develop sophisticated tools that can monitor what is happening in the physical world, while at the same time making forecasts and fulfilling other sophisticated processing functions regarding the future behaviour of systems. Over the course of 2021, LINKS undertook or started work on projects aimed at producing digital twins for telecommunications systems (fibre optic networks), logistic systems (agri-food chain), energy networks, vehicles, machinery and advanced aerospace engines.

19

Quantum Computing

Progress in Quantum Computing (QC), which is approaching a stage of maturity that will make it applicable to real-world computing and secure telecommunications cases and systems. Applications that require a high degree of computing power need to be redesigned in order to fully benefit from the Quantum Advantage. LINKS strengthened its network of contacts in the QC sector in 2021 by virtue of projects that led to partnerships with Consorzio CINECA (Bologna) and the quantum platform proposed by the company PASQAL (Paris).

User authentication

Digital services requiring user authentication are rapidly spreading: the number of portals that offer these services has been growing for many years. Some of these services require unequivocal authentication (e.g. financial services, online banking, government services). Access to these “critical” services still requires users to be positively identified by an operator: to obtain authorization to use the corresponding portals, it is therefore normally necessary to go in person to a bank, post office or other public office, which can be inconvenient and inefficient. The user recognition process therefore needs to be automated, and this is now possible thanks to Machine Learning techniques applied to facial recognition, which deliver excellent results in terms of fraud detection. The skills developed at LINKS in recent years have enabled us to meet this need, and a major project relating to this type of innovative service was launched in 2021.

Digital technologies in the medical sector

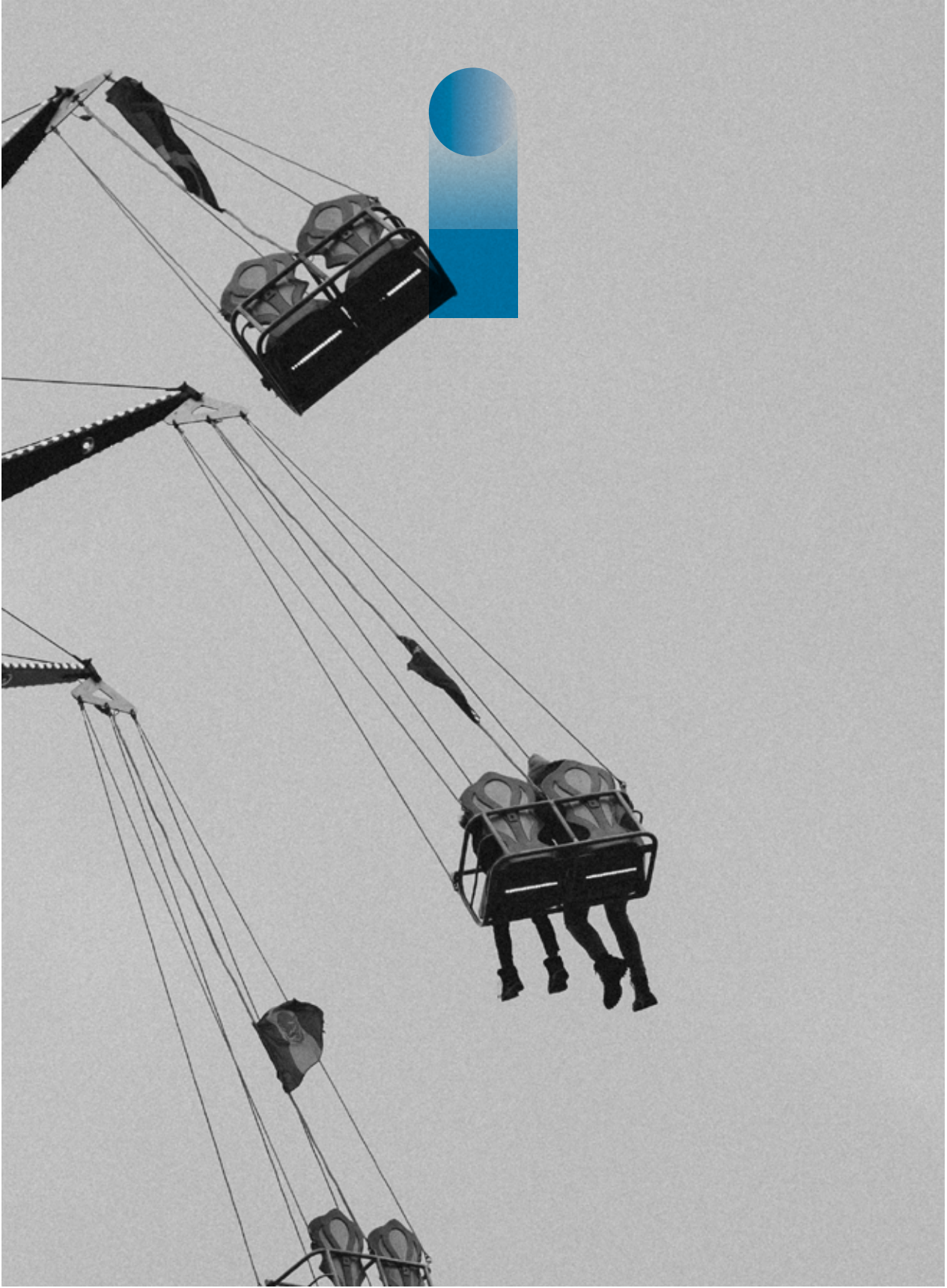
The increasing reliability of digital technologies has prompted further uptake of them in the medical sector: in 2021, LINKS studied both advanced services for patients and healthcare professionals, and sophisticated applications, such as the one mentioned earlier relating to the design of a robotic limb, which was made possible by the collaboration of robot technologies, sensors, advanced data transmission and sophisticated data processing based on paradigms typical of Artificial Intelligence.

Some of the activities carried out with our research partners and relating to the technology trends set out above have led to significant achievements in 2021:

1. For the third year running, LINKS's researchers, in conjunction with colleagues from the University of Southampton, created a demonstrator which beat the record distance for fibre optic transmission, by reaching (and in certain conditions exceeding) 4,000 km (the High-Performance Computing - HPC section has further details). The success was ratified at the Optical Fiber Communications (OFC) conference in Washington, DC. The record in 2020 – set by the same team and officially recognized at the same OFC event in San Diego – was “just” 600 km.
2. The On-Board Units (OBUs) and Road-Side Units (RSUs) developed by LINKS in recent years are now stable enough that their use in real-world installations can be evaluated: three installations have been operating for several months on Italy's A32 motorway, and the 5G-IANA project (self-driving vehicles, 5G, connected vehicles) moved into the operational stage in 2021. The project involves many use cases with international partners that will be based on the devices designed and developed by LINKS (thanks to the open nature of those devices, which make them adaptable to and interoperable with other systems).
3. In the HPC sector, LINKS embarked on in-depth studies of the orchestration of computing resources into complex systems (including Computing Continuum systems) in 2021, by building on the skills it has acquired from working on research projects in previous years. This competence was acknowledged through the approval of the ACROSS project (started in 2021), which is coordinated by LINKS and includes prestigious partners such as the Max Planck Institute, Cineca, CINI, INRIA, Bull and GE-Avio.

Two in-depth sections at the end of this report focus on two emerging sectors of technology that were recently added to the existing list of sectors covered by LINKS's researchers: the first introduces the new paradigm of Web 3.0 and the Internet of Value and some of its practical applications, while the second describes the main research fields within the Quantum Computing sector in which Fondazione LINKS is active.





Advanced Computing, Photonics and Electromagnetics.

22

The Advanced Computing, Photonics and Electromagnetics (CPE) domain encompasses mutually complementary competences in the sectors of High Performance Computing (HPC), photonic applications (not limited to conventional telecommunications applications, but also relating to sectors such as the study of new materials for the production of sensors and biomedical instruments) and the design of antennas for special applications (again, not limited to data transmission).

The sections below provide an overview of the main research activities carried out in 2021 by this highly multidisciplinary group.

HIGH-PERFORMANCE COMPUTING

From a technological and scientific viewpoint, the Advanced Computing research team covers four macro subject-fields:

- The study of models, applications and convergence between Big Data and HPC.
- Computing Continuum architectures, for which the skills originated from the study of Cloud systems, before evolving to include the Edge part. This subject-field also includes skills and activities in the low-power computing sector, which have been acquired over the years and used, for example, in joint activities with STMicroelectronics.
- The orchestration of resources into complex systems with disparate and sometimes conflicting goals and requirements (optimization of energy consumption, optimum management of computing capacity, etc.).
- Quantum Computing.

ACROSS Project

The four subject-fields are well represented in the ACROSS project coordinated by LINKS, which started in March 2021 and has provided an excellent opportunity for extending the foundation's network of contacts, in view of the fact that various large companies are members of the Consortium. The project is an Innovation Action, in which LINKS's researchers have also managed to propose advanced research topics (the most salient of which are activities focusing on the evaluation of computing solutions based on neuromorphic architectures). The key topics covered by the project include orchestrating resources in the context of the Computing Continuum, while

at the same time overcoming the batch work paradigm, which needs to be reviewed in the light of new trends. One of the drivers of this evolution is the advantage that derives from the interaction between HPC and AI, which is a direct result of the considerable interest that Machine Learning and Deep Learning are attracting. In this new way of working, there needs to be an interaction between various tools and algorithms, with feedback techniques that result in high levels of inefficiency in the batch model. Modern applications are made up of different jobs that need to be run concurrently and in interaction with each other, and that also have different needs in terms of computing resources (e.g. the best architecture for the training phase is GPU-based, whereas simulation tasks, such as those relating to fluid dynamics - CFD - benefit more from different architectures).

The macro research field of ACROSS is the **convergence of Big Data, AI and HPC**, and the project deals with these issues while also taking account of the need to respect the presence of legacy systems that cannot be easily updated or replaced.

When orchestrating resources and applications into a complex, distributed system, account must also be taken of other trends that impose specific requirements:

- some resources are Cloud-based, so the orchestration tool needs to be able to interface with that type of architecture;
- the most advanced computing resources also include resources that implement the Neuromorphic Computing paradigm. The corresponding devices need to use specific toolchains, and the orchestrator needs to be able to offer them. Another challenge faced by researchers studying Neuromorphic Computing techniques is the difficulty of accessing such architectures and/or their chips. To overcome this problem, an internal partnership with the photonics team was established for the purpose of designing FPGA systems that replicate neuromorphic architectures. The ultimate goal is to make the orchestrator capable of managing this type of resources as well.

23

The ACROSS project manages access to computing resources in a layered manner, enabling the best systems on a time-by-time basis, according to availability (neuromorphic HW, GPU, FPGA, etc.): the general objective also includes being able to insert heterogeneous HW into orchestration logics, while also taking account of the legacy ecosystem, if there is one.

One of the results already achieved by the project is a significant speed-up (30x) of code originally written for traditional architectures (CPU) and brought to GPU. In Matlab, the original code implemented a processing cycle linked with CFD simulation of turbine blades of an aircraft engine: rewriting it in Python using a specialized library to handle distributed matrices has reduced execution time and resource usage from 1 hour on 25 nodes to 23 minutes on two nodes.

Other topics of interest in the evolution of HPC are the communications between nodes collaborating on the solution of a problem and the reduction of consumption (sophisticated machines consume as much as 50MW!). HPC know-how can also be applied to other problems, as in the aforementioned B-CRATOS project, in which electrical signals generated in the brain need to be translated into suitable signals for actuating a mechatronic limb.

The system is based on AI/ML algorithms: an HPC architecture is used for their training, while a 5W board is sufficient for operation (inference). The signals are transmitted using the adipose tissue of the user: once they reach a predefined end point, the signals are processed by the electronic card dedicated to the AI, which translates them to make them suitable for actuation. Feedback is generated by receiving signals from the sensors on the robotic limb (including artificial skin covering the limb) and sending them to the brain by means of an implantation technique.

Quantum Computing

The activity embarked upon three years ago as a technological and scientific investigation has been consolidated through a partnership with the start-up Pasqal, the supplier of a Quantum solution based on Neutral Atoms, in which the team is involved in the formulation of questions of industrial interest relating to complex optimization problems such as graph colouring, and their resolution through the implementation of quantum algorithms. The

work with Pasqal is also evolving into the joint development of further algorithms/methodologies applied to the aerospace, life sciences and additive manufacturing sectors.

MATERIALS AND TECHNOLOGIES FOR PHOTONICS

Quantum Key Distribution

The internet age has made it vital to develop sophisticated cryptographic systems that are capable of providing a high level of data protection and that do not become quickly vulnerable to the solutions that technological progress brings. While a conventional computer currently takes years to intercept an encrypted message, all this will change with the advent of quantum computers, which will be capable of breaking complex codes in seconds. The only defence against them will be **Quantum Key Distribution (QKD)**, which encodes information about quantum states of light and makes it possible to detect a potential intrusion by virtue of the fundamental laws of quantum physics.

Taking up this challenge, Fondazione LINKS and the Italian National Institute of Metrological Research (INRIM) in Turin have forged a scientific partnership that gives them a crucial role in the development of quantum technologies on optical fibre and that – ambitiously – will help bridge the technological gap that separates Piedmont from Italian and European companies and research centres that have long been working on and investing in cybersecurity solutions based on quantum mechanics. The main objectives of the partnership are to develop and test QKD systems on optical fibre, to engineer the technological solutions already available at INRIM and to integrate them with the fibre networks and infrastructures that are already installed and in daily use for telecommunications.

Very high-capacity, long-distance fibre connections

The use of coherent optical systems for long-distance and high-capacity transmission has proved to be a successful technological choice since it was first implemented, just over a decade ago. However, there is still room for substantial improvements, which are made possible, first and foremost, by real-time physical-layer modelling, thereby creating a de facto digital twin of the optical network. In 2021, the Polytechnic University of Turin, Fondazione LINKS and CISCO Photonics continued their collaboration aimed at formulating and experimentally verifying approximate analytical models capable of correctly estimating the non-linearity effects that characterize optical fibre and facilitating real-time control and optimization of the physical layer. The study aims to fine-tune these models so as to make them usable for next-generation optical systems with at least twice the transmission bandwidth that is currently available. For low-complexity, real-time reconfiguration of these new optical systems, continuous automatic learning of the propagation conditions is required: with this in mind, experiments were conducted in 2021 to design and validate artificial neural networks capable of predicting the evolution of the optical power of the signals propagated in the fibres.

Study of innovative hollow-core fibres

Optical networks worldwide are now based on a special type of fibre known as single-mode optical fibre, which is able to transport information at high speed by channelling the light emitted by a laser through a glass filament. Due to the nature of glass and its physical properties, however, the optical signal propagates more slowly in glass than in air.

To overcome these limitations, optical technologists have recently proposed using special fibres known as **hollow-core** fibres, which mark a major step forward for the technology. With an internal structure designed to force the propagation of light through an air-filled core, hollow-core fibres are capable of reducing signal propagation delay by 50%. Of the numerous potential applications of this technology, ultra-broadband data transmission is likely to have the highest scientific and industrial impact. Transmission experiments on latest-generation high-core fibres are therefore the focal point of a collaboration between our foundation, Southampton University, Lumenicity, CISCO Photonics and the Polytechnic University of Turin. A significant increase in transmission distance has been achieved in the LINKS laboratories, smashing the previous record of 75 km, set in 2015. Experiments conducted at the foundation have demonstrated connections over record

distances using hollow-core fibre, ranging from 340 km in 2019, to 620 km in 2020, up to the current record of 4000 km. The partnership's next goal is to demonstrate an increase in fibre transmission capacity, using optical bands that are not accessible using glass fibre.

Fibre as a distributed sensor

Work started in 2021 on exploring a topic set to attract growing interest, namely Fibre Sensing, which uses optical fibres as a kind of environmental nervous system. In applications of this type, optical fibre is not only used for data transmission but also serves as a distributed sensor capable of detecting vibration, disturbances and changes in the environment in which it is located. For example, optical cables can be used to monitor and study earthquakes or traffic conditions. Initial experiments in this area are already under way at the LINKS laboratories, and new partnerships are taking shape.

Fibres made with special glass

Thanks to a partnership with the Polytechnic University of Turin's Department of Applied Science and Technology (DISAT), this activity extends across the entire value chain that runs from the material, all the way to the device: the researchers from LINKS and the Polytechnic are working on the design, development and characterization of special optical fibres for the production of components for telecommunications and sensor systems. 2021 saw the completion of a two-year research project, carried out with the Laser Zentrum in Hanover, on the development of a new generation of lasers for detecting gravitational waves (LIGO), involving the design, production and characterization of a 1.5 µm optical fibre amplifier based on a composition of erbium-doped phosphate glass made specifically for this research initiative.

Multifunctional optical fibres for biomedical applications

Highly innovative optical fibres have various applications in the biomedical sector: a significant example of these, being studied by LINKS, is fibre capable of combining the transport and collection of light signals, with sensing functions and the release of drugs or other chemical substances. The initiatives being carried out in this field include the **EU-MSC PHAST project** ("Photonics for Healthcare: multiscAle cancer diagnosiS and Therapy"), which studies the use of biophotonics for the diagnosis of tumours. Led by the University of Parma, the project is being carried out by a group of 22 partners, including two hospitals and eight companies (Philips, Zeiss, etc.). This four-year project involves high-level training and tuition for 15 young researchers, by means of a top-tier multidisciplinary doctoral programme. One of these doctoral students is a researcher on the staff of LINKS, who is being supported by the economic resources generated by the project.

Special materials obtained using lasers

Researchers studying innovative materials are showing increasing interest in the use of laser sources for marking, colouring and texturizing metals, polymers and ceramics. Thanks to a partnership with Datalogic and the availability of regional funding, it became possible in 2021 to obtain various types of ultra-short pulse lasers in the infrared, visible and ultraviolet spectra. These laser-based techniques make it possible to design and produce surfaces with specific functions (hydrophobic, self-cleaning, decorative surfaces, etc.), as well as precision micro-machining. One of the initiatives of this type launched in 2021 involved the production of **Laser-Induced Graphene (LIG)** from polymers, which is a quick and cost-effective way of producing "graphene foam", a three-dimensional material with typical characteristics of this material. A partnership was established in this field with researchers from LINKS, who are studying the use of graphene to produce micro-antennas, electronic devices and wearable sensors.

COMPUTATIONAL ELECTROMAGNETISM AND SPECIAL ANTENNA DESIGN

Research projects and activities

In the Computational Electromagnetism and Special Antenna Design sector, 2021 saw the consolidation of joint initiatives both with the Polytechnic and with a number of industrial partners. Particular effort went into strengthening the relationship with IDS, one of the companies with which LINKS has long been carrying out joint projects aimed at developing software modules to extend their electromagnetic modelling and simulation

tools. IDS was acquired by Fincantieri in September 2021, and the change of strategy facilitated the negotiation of new collaboration initiatives, which now also include the design of special antennas.

One of the trends that rose to prominence in 2021 and is set to dominate innovation in the antenna sector for the next few years is the study of technological solutions for pointing **non-geostationary satellites (GEO and LEO)** for supporting internet connectivity. These satellites pose a major technical problem, because the antenna has to “track” the satellite as it moves in the orbital plane and therefore changes both its latitude and longitude.

The ESA project submitted by 5GEmerge, a very large consortium encompassing about 40 partners, including various broadcasters and manufacturers, is specifically dedicated to this subject. LINKS is the only research body involved, and benefits the consortium with its expertise in smart antennas.

The aim of the project is the design and production of prototype antennas capable of performing steering operations by means of beam forming (with no moving mechanical parts), limited for the time being to low speeds and the vertical plane. Rotation on the azimuth plane (at right angles to the gravitational plane) is currently still performed mechanically.

One of the main drivers of research interest in this field is the foreseeable diffusion, in the coming years, of solutions that require connectivity on systems in motion (vehicles, aircraft, ships, etc.), thus further complicating the problem. Producing antennas with this level of performance using traditional technologies (mechanical movement) would make them unsustainably costly to install - for example - on vehicles. The cost of antennas made with beam forming techniques, however, could be low enough to make them suitable for use in automotive applications, for which a cost in the order of a few hundred euros is acceptable for instrumentation of this type.

Some of the most innovative technologies for the production of antennas with beam forming capability also include **metasurfaces**, i.e. surfaces made of materials whose physical characteristics can be electrically controlled (e.g. liquid crystals, the technology to which the new contract with IDS relates). The increasing complexity of antenna technology also makes it necessary to study systems and instruments for designing them automatically, starting from the expected performance (radiation diagram).

This is an extremely complex problem, which is currently still undergoing research. Despite its low TRL, however, it remains of interest even to major telecommunication companies, which are beginning to examine the question of how to construct new Base Transceiver Stations (BTS) for radiomobile connectivity.

Another major project funded by the ESA went live in 2021, and Spidercam commissioned LINKS to carry out part of the work on it. The aim of the project is to produce a system for validating large antennas intended for satellite connectivity. Built entirely inside the large anechoic chamber at the ESA's technology centre in Noordwijk (Netherlands), the system consists of a sophisticated motorized infrastructure (made by Spidercam), which allows three-way movement of the probe that detects the signal emitted by the antenna installed on the satellite, which is fixed.

The brief is to produce a high-precision system at moderate cost that is capable of “positioning” the probe in the measurement space with extreme precision to evaluate its performance. Existing systems for this type of measurement, but based on different technologies, have costs in the order of one million euros, while this project aims to produce an innovative system at a quarter of that cost. The higher the operating frequency of the antenna to be measured, the greater its positioning accuracy needs to be, and in this case it must be less than one centimetre. At 10GHz, the tolerance needs to be approximately 3 mm.

Artificial Intelligence, Data and Space.

In the wake of the recent reorganization, the AI, Data and Space Domain (ADS) was formed by integrating the AI research area with the area assigned to satellite applications, such as navigation and earth observation. In line with the new guidelines, particular attention was paid in 2021 to identifying assets which can be exploited, in conjunction with the Accelerating Competitiveness Goal (ACO), to maximize their value from the viewpoint of interested partners.

27

AI AND DATA SCIENCE

Our know-how in relational systems and their ability to support users with a sophisticated, enjoyable user experience was fine-tuned on the strength of projects such as **Easy Rights**, which focused on social inclusion. In this specific case, the target users are migrants, whom the project is intended to assist by providing summaries of some of the main administrative procedures of interest to them. A dedicated chatbot was released in 2021, since chatbots are being used with increasing success in various contexts among a population that is now accustomed to interacting via chat channels on social networks.

The ability to analyse texts taken from social networks to extract summary information from them about the subject to which they relate is applied in numerous projects: these include **MEDIAVERSE**, which studies text annotation techniques designed to help implement search and indexing services that enable the text to be used more efficiently and effectively. The project refers to a decentralized architecture in which content remains on users' computers (or in any event on a large number of distributed nodes), thus implementing a paradigm aimed at testing a new alternative to the centralized model proposed by the large companies that manage the social media platforms that we know. Content search and indexing will also be innovative, with multi-channel access, using images in addition to text, for example. The project moved into the operational stage in 2021 and will reach completion in 2023.

The projects launched on the basis of know-how in AI and Data Science include the collaboration with CREDITSafe, which gave the LINKS team a chance to enhance its knowledge of **"time series"**, in other words, the collection and processing of historical data for the purpose of studying the long-term evolution of specific phenomena, including future trend forecasting. The project focuses on processing information on credit risk,

by assessing the development of the main economic and financial parameters of the enterprises that received loans.

Some of the results obtained from the research projects on which the Domain has worked in past years have been analysed to assess the possibility of transferring their value to partners outside the consortia formed to carry out the projects. Some of the results obtained from projects on emergency management fall into this category: again, technologies such as the analysis of satellite images or texts published by users (crowdsourcing) and chatbots have formed the basis of the solutions developed, which organizations such as the regional Civil Protection Department and CSI Piemonte are considering adopting.

In general, the Domain's researchers have stepped up their capacity, in 2021, to design solutions geared towards market exploitation.

SPACE APPLICATIONS

The most relevant data sources for emergency management projects certainly include information from satellites, such as time information provided by the Galileo system (which plays a crucial role in assessing the position of receivers) and data relating to earth observation.

The Domain has been joined by the research team historically dedicated to satellite navigation technologies, which has taken care of the Galileo project since its design stages and has achieved a level of expertise and a reputation, over the years, that enable it to take a leading technical-scientific role in activities of interest even to large companies. Initiatives of this type include a major project with Leonardo and various activities carried out with the ESA, especially in relation to topics falling within the scope of the second generation of Galileo-based systems (G2G).

Position calculation techniques and accurate time information obtained from the Galileo system also form the basis of a significant collaboration with the LINKS Cybersecurity team within the framework of the **European ROOT project**: in this case, the synergy is focused on the "security by design" of devices that receive signals from the Galileo system, which, by virtue of a collaborative, decentralized approach, are capable of countering cyber attacks intended to instrumentally modify time and location information (spoofing).

In the field of earth observation too, the Domain continued, in 2021, to carry out activities that make productive use of the expertise acquired in past years in the use of images - and other data - originating from the Copernicus satellite system.

This is also a topic of considerable interest to ITHACA srl, which plays a dual role in relation to the ADS Domain, both as a provider of large amounts of useful data for training Artificial Intelligence algorithms, and as a potential beneficiary of the technology transfer of solutions that make use of those algorithms.

MANAGING EMERGENCIES

The team responsible for studying emergency management solutions has started exploring new fields of application in addition to its long-established work on responses to natural disasters such as fires (**SAFERS** project) and floods: two further projects (**APPRAISE** and **STARLIGHT**), focusing on city safety and the fight against microcriminality, were acquired in 2021. STARLIGHT is especially significant, as it is a European Commission flagship project on AI for Security. As with all of our foundation's research teams, European projects continue to play a key role in the ADS Domain: our researchers seek opportunities to procure scientific

activities in that context, while at the same time offering their services as project leaders, including for large-scale projects, as in the case of SAFERS, which is coordinated by one of the Domain's Programme Managers. Collaboration with companies also yielded significant results for the ADS research groups in 2021: in addition to the aforementioned project carried out with Leonardo, a major collaboration with ARUBA is now under way, on remote on-boarding, in other words the use of AI and Machine Learning techniques to verify the identity of users who subscribe to online services. The identity verification service is managed autonomously by the user with a guided but automatic mechanism, in order to limit the need for human intervention.

Moving onto internal activities carried out to develop or strengthen specific areas of application of AI technologies, two outstandingly successful demonstrations of the future-driven internal **MusicAI** project were held in 2021. The project was launched in 2020 to tackle the challenge of training an artificial intelligence system in the emotions aroused by a piece of music, and then representing them in the form of digital pictorial works. The two demonstrations were held at the Castello di Guarene (in the province of Cuneo) and at the Polytechnic University of Turin.

The Domain also plays a very active role in its collaboration with the University of Turin and the Polytechnic University of Turin, under which it carries out teaching activities and provides support every year to various candidates working on theses or doctoral research programmes. Two researchers from the staff of LINKS completed or continued their PhD programmes at the two Turin-based universities in 2021. Some of the courses in which our researchers take part as lecturers also include projects for students at companies such as Accenture Labs France in 2020 and In-Recruiting in Turin in 2021. More than 10 students have taken part in initiatives of this type, some from the Polytechnic and others from training agencies with which LINKS has long-standing working partnerships.



Fabrizio
Dominici

Connected Systems and Cybersecurity.

30

As part of the reorganization implemented in July 2021, skills relating to pervasive technologies, the cybersecurity of connected objects and enabling technologies for connected and autonomous mobility systems were aggregated, giving rise to the Connected Systems and Cybersecurity domain (CSC), thus leading to major synergies both in the study of technological components and in their re-use in different sectors. The sections that follow set out the main activities carried out and results achieved in 2021 in these three macro-areas of research.

CONNECTED AND AUTONOMOUS MOBILITY SYSTEMS

ICT4CART project

Culminating in a final event at the ITS European Council in October, ICT4CART was a high-profile project that dominated 2021 and was the focus of a major effort by the research team. By taking part in this project, LINKS significantly extended its network of partners and experts in **Connected Mobility**. A close and important relationship was forged with ICCS (a Greek research centre), the project coordinator, with which three other proposals for European projects have been prepared, two of which have already been funded.

The topics covered by the project include cooperative communications in autonomous driving applications. The project also provided an opportunity to make significant progress on two devices (OBU and RSU) designed and produced by LINKS, which are two strategic assets for our foundation. The devices had already been used in previous projects (e.g. **AUTOPILOT**) but were not yet mature, and required considerable customization to adapt them to a specific context. They now have a much higher level of stability: two RSUs were installed on the Brenner motorway in October for the purpose of conducting the tests involved in the project. They are equipped with cameras and electronic cards to manage both short-range (WiFi and CV2X) and long-range (5G) communications.

A demonstrator based on our devices has also been installed in an urban environment in Verona, to recognize the presence of pedestrians and vehicles arriving at a junction at which they are not visible: in this case, the RSU detects the arrival of pedestrians and vehicles and informs the driver and the advanced driver assistance system (ADAS).

The flexibility with which the devices were designed also makes it possible to provide an on-board GPU, thus enabling tests that can be used to compare scenarios in which the computation is performed on the devices, or in edge or cloud computing.

The project partners include WINDTRE, which has provided both the electronics for the Edge servers that are connected to their sales network in the project, and the necessary SIM cards to connect IoT devices. The resulting performance is outstanding, with a guaranteed RTT of less than 30ms.

The use cases described above, which form part of the ICT4CART trials in Italy, are complemented by others in progress in other countries, such as Germany and Austria. More specifically, with Austrian partners, the collaboration focuses on cross-border solutions: in this case the architecture is designed in such a way that the On-Board Unit connects to one broker device in Italy and one in Austria, using 5G technology.

Collaboration with ETSI

Reference to standards plays a crucial role in the automotive and connected mobility sectors: the relationship established over the years with ETSI, with which discussions are under way for the standardization of cross-border communications, is therefore valuable. In 2021, this collaboration enabled LINKS to make major contributions to the **MEC30 standard** (MultiAccess Edge Computing), in collaboration with Intel. Participation in interoperability sessions at ETSI (plug-tests), in which LINKS takes part with the OBU and RSU cards, have always yielded positive results, thus ensuring that our devices are ready for real market exploitation.

5G-IANA project

A further highlight of 2021 was the operational launch of the 5G-IANA project, in which our devices gained important recognition: where possible, the use cases envisaged by the project will be based on our OBUs and RSUs. Part of the advantage that has been recognized in our systems is the flexibility and reconfigurability that they offer, as a result of their open-source design.

Cybersecurity functions (embedded trusted computing) have been included in the relevant LINKS architecture for connected mobility, by forging a partnership with the LINKS team that deals with that sector: the OBUs and RSUs authenticate themselves by remote attestation to Edge servers, which in turn perform remote attestation to the Cloud.

CYBER PHYSICAL SYSTEMS AND INDUSTRIAL IOT

One of LINKS's main assets, deriving from studies and research programmes embarked upon several years ago, is the application of emerging **radiocommunication technologies to indoor positioning**. This is a continuously evolving field, in which LINKS's researchers exploit advances in enabling technologies to improve system performance. In 2021, for example, expertise in UWB technology was extended by applying the Angle of Arrival technique to the positioning system, in addition to the more conventional Time of Arrival technique (ToA). This technology has been applied to the SHELLO project for the safety of operators using trucks with a movable rear bed.

On another front, the scope of positioning has also been extended by using **collaborative techniques** that have already been tested in other projects (e.g. CPSwarm): in this case, drones or various vehicles collaborate to "carry" the positioning signal into places where there is no direct visibility of satellites (tunnels and the like). One vehicle remains in the GNSS coverage area, while the one engaged in the operations combines and correlates the information from the GNSS node with the information from the on-board inertial sensors (the "mobile anchor" principle). The solution developed by LINKS was proposed in the SENECA project, whose aim is the Technology Transfer of large-scale indoor positioning solutions.

These activities are also carried out in collaboration with ICT companies with which LINKS has signed a non-compete agreement limited to specific application sectors, while retaining the possibility of continuing to

develop the system in subsequent research projects.

Applications of indoor positioning techniques include equipping rovers and other vehicles with the ability to map their environment autonomously, thus offering a solution for situations in which vehicles lose track of their exact location. In this case too, the mapping service can be made collaborative and the UWB technology can be used by the various vehicles to reconstruct an overall map (since each one knows its own position in relation to the others).

2021

Further advances in collaboration between **robotic systems** or between robots and operators were made in 2021: the Foundation's main interest lies in the operator's viewpoint, and involves the study of solutions based on wearable devices for detecting location, predicting movements etc. In this case, wearable sensors and other sensors installed on robots transmit the information to a central system that processes it and then issues actionable information, warnings, etc.

Collaboration is also a key aspect of scenarios created using swarms of drones or rovers, in which vehicles need to agree on how to handle certain operations by communicating with each other (e.g. which parts of a complex task should be assigned to each of the drones/robots, how to divide the work area between different drones/robots, etc.). As an additional challenge, these applications involve the need to "translate" a task expressed in a high-level language into elementary actions that can then be assigned to different robots/drones.

The design and use of autonomous systems requires rigorous attention to cybersecurity: although covered in greater depth by a dedicated team, cybersecurity is always taken into account in projects involving the use of robots and IoT devices.

32

CYBERSECURITY

2021 was a year of consolidation for the research group dedicated to the cybersecurity of networked objects, which reinforced its internal skills, and its partnerships with the Polytechnic University of Turin, CINI and external partners.

The studies launched in 2019 on the subject of secure communications, management of the identity of objects and their integration into Trusted Execution Environments, have been exploited by producing demonstrators that make it possible to witness the contributions of the various system components first-hand.

The collaboration with the Polytechnic and CINI involved providing support for various thesis programmes (some to be activated next year) that give students the opportunity to work on challenging problems that form part of a medium-to-long-term roadmap and on extremely innovative cybersecurity systems, for which there is clear market interest.

As far as collaborations with companies are concerned, the agreement with STMicroelectronics for the development of the solutions studied at LINKS on their rapid prototyping boards has been renewed.

A significant agreement has also been signed with the IOTA Foundation, the organization that designed and developed IOTA, the Distributed Ledger Technology (DLT) specifically dedicated to managing data and communications relating to the IoT: in this case, the SW designed and developed at LINKS, which uses the IOTA architecture for managing secure communication and the identity of objects, has been integrated into the libraries made available to IOTA community users.

Future Cities and Communities.

The Future Cities and Communities Domain (FCC) studies innovative processes and solutions for the management of future cities and communities. These solutions derive from the convergence of technological skills (modelling, simulation, Distributed Ledger Technologies [DLT]), town and country planning skills (mobility, logistics, environment, energy), and impact and sustainability assessment skills. Some of the research activities represent the natural progression of previously launched projects, while others are new activities involving skills acquired after the reorganization in July 2021.

33

MOBILITY AND LOGISTICS

The second phase of the **MobItaly project** was carried out in 2021. This involved developing the Proof of Concept of a tool that facilitates the offer of dedicated and on-demand collective transport, with flexible planning of both routes and timetables. The Domain took responsibility for defining the optimization algorithm aimed at automatically creating timetables, routes and stops for transport services that adapt to user bookings in order to maximize the number of users served, with the smallest possible number of vehicles and kilometres travelled.

The research team has also worked on topics relating to Autonomous Mobility with the **SHOW project**, in which FCC is coordinator of the Turin pilot project, Italy's first trial of self-driving shuttles operating on public roads. In addition to designing the case study, coordinating the work of about 10 partners (including GTT, Navya, Swarco, 5T, Reale Mutua, Turin City Council and Ioki), and managing relations with the Italian Ministry for Economic Development (MISE) and the Italian Ministry of Infrastructure and Sustainable Mobility (MIMS), the Domain drew up the requirements for the pilot project and will evaluate public acceptance of this new technology. In the same context, analyses of the interaction between self-driving vehicles and other road users (non-connected cars, pedestrians and cyclists) will be conducted in conjunction with the Connected Systems and Cybersecurity Domain team, which takes care of the corresponding enabling technologies.

The FCC Domain also addresses the energy-related aspects of mobility, in particular through activities aimed at studying solutions to promote the development of electric mobility. Launched in 2020, the **INCIT-EV project**, under which numerous activities were also carried out in 2021, involves the design and implementation of

innovative EV charging posts to improve the user experience. This Domain's contribution was to draw up a list of requirements for posts, by conducting a public survey and developing a Decision Support System to help decision-makers with the positioning and sizing of charging points in the city. The project also involves road-testing a charging hub in Piazzale Caio Mario, in Turin, for cars and light commercial vehicles with 10 low-power posts, 1 newly designed ultra-high-power post and 2 plates for wireless charging, all connected DC-DC to the tram power grid to make use of the energy recovered from vehicle braking. FCC is developing the power flow control algorithm of this micro grid.

The main project in which the Domain has been engaged on the logistics front is **TYPICALP**, which entered its fourth year of operation in 2021, and whose aims include optimising logistics management in the transport of typical products from the milk and dairy sector in a cross-border area spanning Italy and Switzerland. The project's participants include the CPE Domain, which takes care of the part relating to information systems to support the envisaged services. In this case, optimising the logistics involves setting up a platform that incorporates a marketplace for the sale of typical products and ensuring efficient, sustainable management of the resulting shipments by sharing delivery vehicles and optimising loads and routes. The project also covers Change Management in the way the sector operates, as transport is often intentionally managed by individual producers independently, because logistics and deliveries serve as a means of conveying marketing messages and seeking new customers.

ICT FOR ENERGY AND PEOPLE

In the energy sector, the Domain was engaged, in 2021, in the design and construction of a digital twin of the electricity distribution network of an entire valley in the Autonomous Province of Bolzano, for the application of control algorithms for the purpose of "islanding", i.e. the system by which communities with enough sources of energy generation and storage can temporarily disconnect from the distributor's network (**FLEXIGRID** project). In this case, the operator concerned, which supported the trial, is the Bolzano-based company EDYNA.

In the Distributed Ledger Technologies and Energy sector, a **project entitled Data-Cellar** is under way, which aims to develop the future Energy Data Space for the Gaia-X European Cloud platform in order to promote the development of Energy Communities. As part of this initiative, FCC will build a marketplace for energy data and artificial intelligence models based on blockchain technology. By making use of mechanisms of tokenization, blockchain will make it possible to put in place a system that rewards public and private entities that belong to the energy community. Everyone who contributes AI models or data will be rewarded with a number of tokens, thereby encouraging communities to act for the good of the ecosystem itself, by providing quality data and models. The year will also see the continuation of the **Mediaverse project**, in which FCC has used blockchain technology to simplify the process of recording and tracking rights over media content published by citizens, through the development of Smart Contracts (SCs) that automate the management of licences.

Furthermore, **remote health monitoring** applications have been developed to monitor patients and simplify interaction between patients and doctors, including IBD Tool, for monitoring patients suffering from chronic inflammatory bowel diseases and SINTEC, to estimate systolic and diastolic blood pressure non-invasively by analysing and processing physiological electrocardiographic and photoplethysmographic signals transmitted by wearable devices.

CLIMATE CHANGE, CITIES AND THE ENVIRONMENT

Another field of study and research covered by the Domain is the environment and sustainable town and country planning, both of which increasingly cut across a wide range of other initiatives. Nature-Based Solutions (NBS), in other words design solutions that take advantage of natural phenomena to mitigate the impacts of climate change, are of particular interest in this respect. Interventions of this type, which often relate to landscape management in public spaces, go by the name "urban acupuncture" to highlight their focus on clearly defined areas.

The co-design of the most appropriate interventions is based on data provided by cities in relation to parameters such as air quality and heat islands. Activities of this type are also included in the Central Europe project known as **Salute4CE**, which entered its third year in 2021, and - in a non-urban context - the project aimed at monitoring viticulture quality parameters within the UNESCO Vineyard Landscape of Piedmont: Langhe-Roero and Monferrato: in this second case, the monitoring is carried out by the CPE Domain, while the FCC Domain takes care of analysing the risks and impacts of climate change, and formulating both short-term and long-term prevention and mitigation measures.

The sustainability of cities, meanwhile, is the focus of a joint initiative with the Polytechnic University of Turin's Department of ENERGY - DENERG IEEM and the **Lab for Environment and Energy Innovation - LEEI**, aimed at developing innovative methods and processes for assessing the sustainability of urban and territorial transformations on various scales (from buildings to neighbourhoods, urban areas and metropolitan areas, all the way up to wide-area interventions) throughout their life cycle (design, construction and maintenance) and support decision-making to identify measures for improving the energy efficiency and environmental performance of buildings.



Maurizio
Arnone



In-depth analysis by Enrico Ferro and Alfredo Favenza.

The Internet of Value and the Token Economy

36

Information and Communications Technology (ICT) is often cited as one of the main drivers of innovation in the global economy. As a result, there is often a closer focus on the impact that this technology has on the various sectors to which it is applied, than on the process of change that the technology itself undergoes.

The WorldWide Web itself has undergone several paradigm shifts over the past 30 years. For the majority of users, its first iteration (**Web 1.0**) was a tool for retrieving information through passive use of static web pages. At this stage, the web was mainly used as a one-way, one-to-many communication system, serving much the same purpose as company brochures and newspapers, but tailored to the new digital medium: websites.

In the next stage, the introduction of **Web 2.0** facilitated a widespread process of content creation in which users play an active role in creating and propagating the content generated. This paradigm was enabled by the advent of the platform economy (Facebook, Twitter, eBay, YouTube, Spotify, Airbnb, etc.) which have achieved dense, widespread coverage over the past 20 years, in both geographical and demographic terms. While the platform economy has given a voice and an opportunity to thousands of people, it has also had unwanted side-effects, such as the consolidation of asymmetric power relationships between platform operators and content generators, advertising-based business models that give rise to spasmodic warfare to grab the attention of users (by amplifying messages that are often divisive and based on fear), the transfer of ownership of content produced by creators to platform operators, etc.

Before the advent of Web 2.0, the gradual process of digitization mainly involved texts, sounds and images, leading to what became known as the Information Internet. Within this paradigm, everything that is digitized becomes significantly cheaper to reproduce and distribute, thereby democratising access on the one hand, and demonetising content and work connected with generating it on the other.

Distributed Ledger Technologies (DLT) started becoming widespread in 2008, and made it possible to extend the digitization process to financial infrastructure, thanks to the revolutionary introduction of digital scarcity, i.e. the ability to create non-duplicable digital assets. This gave rise to the **Internet of Value** for managing digital assets by means of smart contracts, in other words software programmes that make it possible to allocate the ownership rights of a specific digital asset transparently and deterministically, on the basis of cryptographically signed declarations.

What are **digital assets**? Digital assets are representations of various types of value, such as energy savings, user attention or loyalty, and voting, ownership or access rights. These assets are represented by tokens, which act as accounting units. To use a more familiar metaphor, you can imagine them as “digital apartments” that can be divided into an infinite number of sub-units, used from anywhere and transferred without the need for any intermediary.

The Internet of Value is therefore a new global infrastructure for storing and transferring all forms of value, based on open code, on which it is possible to build freely and autonomously. The ease of creating new services by re-using and combining existing elements brings a major boost to the rate of innovation, even compared with market sectors that are technology-intensive but more closed and characterized by a higher level of intellectual property protection. Unlike Web 2.0, moreover, where the value generated was mainly internalized by a limited number of large intermediaries, the Internet of Value lays the foundations for building a global social network owned by service developers and content generators, which uses tokens as a tool for incentivization and coordination. In this context, it is possible to implement broader and more granular value distribution logic, with a closer correlation between remuneration and actual input.

The third stage of web development described above paves the way for the emergence of a new economic model – the **Token Economy** – in which tokens take on a central role. In order to be able to take the opportunities associated with this, we need a clearer understanding of the changes that the use of these tools introduces into the formation and management of value chains.

First, tokens can be used as an incentivization and coordination system among the stakeholders who gravitate around the construction of an enterprise (typically, investors, employees, shareholders, and third parties with complementary roles) by causing their interests to align in the direction of a common goal, namely the growth of the ecosystem and the consequent appreciation of the token.

In one of the examples cited in this report on Future Cities and Communities, **blockchain** – the first and most famous DLT – has proved to be the most effective technological choice for creating a mechanism that aligns incentives between the various participants in an energy community. By making use of the characteristic mechanisms of tokens, blockchain makes it possible, in that case, to put in place a system that rewards public and private entities that belong to the energy community. Everyone who contributes AI models or data will be equitably rewarded with a number of tokens, thereby encouraging communities to act for the good of the ecosystem itself, by providing quality data and models.

Another example of a project carried out in 2021, also using token-based incentive mechanisms, culminates in the management of a rural community, by verifying the impacts of the sustainable actions carried out by citizens, and by providing a transparent, certified metric of the level of sustainability achieved by the rural areas involved.

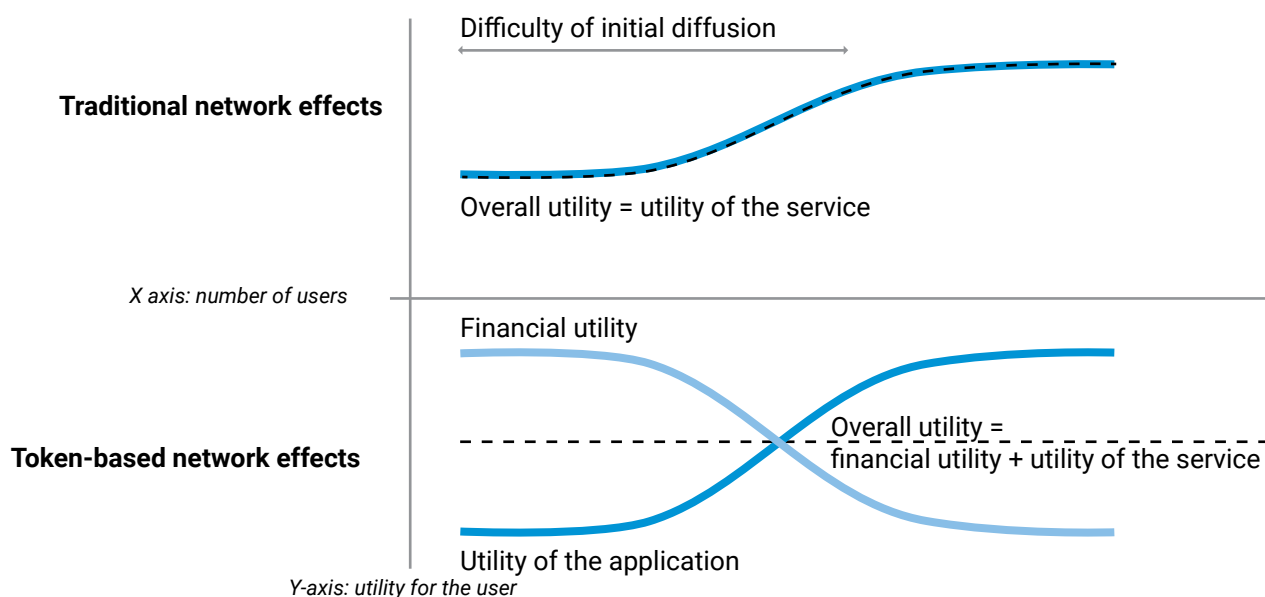
Another way of using tokens involves taking advantage of the characteristic ease with which they can reach the global capital market in order to raise the necessary funds to finance new business activities. **Utility tokens**, in fact, are gradually establishing themselves as a third pillar in the process of capitalization of entrepreneurial activities in addition to debt (rights over assets) and shares (rights over profit), by representing rights to the future growth of the network. One of the advantages of using utility tokens is that they make it possible, from the earliest stages, to socialize the benefits of the network effects that characterize the platform economy and that drive the growth in its value over time.

As a further example, tokens can be used to reduce the initial take-off friction that typically affects the diffusion of innovation, as shown in the graph below.

The use of tokens in designing the network growth process makes it possible to balance the limited initial utility due to the small size of the network with a financial incentive connected with the token's potential for appreciation as the established pool of users who adopt the service in question grows.

Lastly, it is worth mentioning the use of tokens as a tool for protecting and making productive use of **intellectual property in the form of artistic heritage**. More specifically, tokens of a particular type, known as Non-Fungible

Tokens (NFTs) make it possible to create original digital works and certify their provenance and relationship with the author by means of Distributed Ledger Technologies. Over the past few years, this innovation has prompted various experiments in the creative industries that have enabled artists to explore new business



models by creating a direct relationship with their fans and helping them share in the success of their work, as well as benefiting from the secondary market by adding a clause to the NFT contract, by virtue of which commission is payable every time the work is sold.

The selection of examples outlined by no means represents the entire range of opportunities introduced by the Token Economy. However, it is important to emphasize that this new paradigm will enable open innovation to take a step forward by promoting combined, widespread use of co-creation, crowdfunding and crowdsourcing activities. All of these practices were previously available through dedicated platforms, but were rarely integrated synergistically into a single strategy. Decentralized technologies can generate further value when they are used in synergy with Artificial Intelligence techniques: in 2021, LINKS developed a technological reference framework proposing two high-level stacks that highlight potential areas of application in which blockchain and AI can pool their respective characteristics to solve common problems.

In conclusion, the Internet of Value and the Token Economy are two emerging phenomena that will take a few years to permeate Italy's production fabric pervasively. Despite this, for an organization like Fondazione LINKS, whose research and innovation work is focused on IT networks, it is vital to cover the evolution of these phenomena in advance, so as to enable local players to ride the wave of change rather than being overwhelmed by it. From an operational point of view, this means investing to build the multidisciplinary skills that are needed to capture the complexity of the impacts that these new paradigms will generate at an economic and social level.



In-depth analysis by Giacomo Vitali and Paolo Viviani.

Quantum Computing, a new technological frontier

The exploration of Quantum Computing (QC) is one of the new frontiers in the broad field of **High-Performance Computing** (HPC).

The evolution that we are seeing in QC is following the same pattern as the evolution prompted by the introduction of specialized accelerators (GPUs, FPGAs) into data centres, in the wake of the explosion of Machine Learning methodologies. As before, quantum computers are expected to be paired with conventional supercomputers to take advantage of their ability to resolve certain specific and currently intractable problems in a highly efficient manner, thereby accelerating the execution of complex HPC applications globally.

More specifically, the most promising fields of application are the simulation of materials or complex systems, quantum chemistry and its applications to life sciences, combinatorial optimization and IT security.

Fondazione LINKS offers its partners the necessary skills to help them find their way in this complex field, which is constantly and rapidly evolving: in pursuit of this aim, it takes part in projects in partnership with other research and computing centres, industrial companies and small and large enterprises that are positioning themselves in this field or intend to do so in order to close the technological gap with their international competitors (or open up a gap in their own favour), and thus gain competitive advantages in their market.

It is essential to bear in mind that, although certain solutions are already available on the market, this technology is at the pioneering stage and is therefore associated with high barriers to entry in terms of the skills needed to make effective use of it and the constant, rapid evolution of the underlying technologies.

At present, the variety of technologies used by manufacturers makes it impossible to identify a specific technological reference immediately. The available platforms all differ substantially from each other in many respects, thus making it necessary to clearly identify the application problem in order to choose the technological solution that offers the best match.

For the same reason, even the definition of quantum advantage, as well as the standardization of benchmark models, is still evolving. This is the context in which LINKS operates, by developing specific application solutions and guiding and facilitating the development of industrial partners by means of the necessary knowledge transfer.

LINKS also benefits from the synergy between the team of Photonics researchers and Advanced Computing group, which studies quantum techniques relating to quantum communication and, in particular, **Quantum Key Distribution** (QKD), i.e. the study of techniques based on quantum physics for the distribution of cryptographic keys between encrypted optical communication partners.

The success of the QC team is borne out by the reputation that our foundation has gained among leading players in the sector (PASQAL) and major companies with complex problems such as fluid-dynamic simulations: these problems are notoriously challenging in terms of computing power, but can be solved much more effectively by Quantum Computing. Against the backdrop of such rapid technological development, we have started work, with partners of this level, on investigating which quantum architectures are the best match for the various fields of application.

In cases like these, our foundation's objective (and mission) is to match the demand for computing performance with the technological supply, thereby helping our partners to make complex choices in a highly dynamic, rapidly evolving context.





2021

Notes.

42

Annual Report 2021





20
21

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ANNUAL REPORT

Report on operations and results