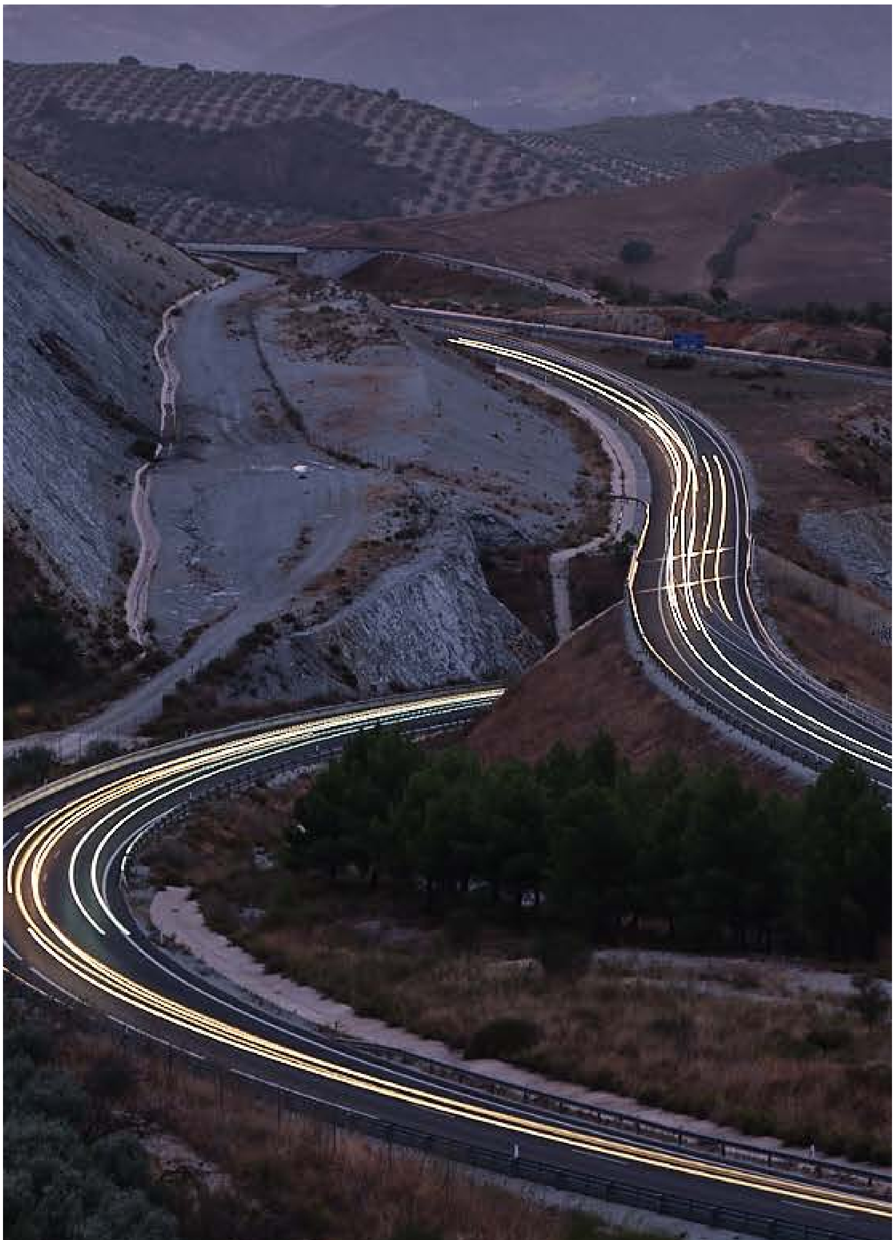


THE ERA OF INFRASTRUCTURE 4.0

How digitalization can help infrastructure to answer the challenges of the post-Covid-19 world

Altermind

VAUBAN INFRASTRUCTURE PARTNERS

FOREWORD BY

GWENOLA CHAMBON,
CEO, Founding Partner

MOUNIR CORM,
Deputy CEO, Founding Partner

Since its inception, Vauban Infrastructure Partners strives to contribute to the sustainable development of local communities and their environments by investing in infrastructure assets in the social, digital, mobility and energy transition sectors. Our mission is to create long-term sustainable value for all our stakeholders–investors, communities, public bodies, employees and industrial partners–by maintaining optimal service quality.

This year, 2020, has a dramatic impact on our daily lives with a global health crisis, which has triggered multiple and unprecedented economic outcomes.

This crisis has confirmed the critical role of infrastructure to ensure the continuity of social and economic life: utilities, telecom networks and hospitals have been essential in this period. Others, such as mobility assets, have suffered significantly from lockdown measures but will play a key part in the recovery of economies and the future of societies.

Besides the impact of the crisis, the infrastructure sector has also been deeply affected by other megatrends, including climate action, geopolitical readjustments, demographic developments, technological innovations, etc.

Among these megatrends, digitalization is potentially one of the most powerful and disruptive for infrastructures. It impacts the infrastructure environment, with the emergence of new competitors, such as digital platforms. It also accelerates the transformation of the infrastructure itself, with the use of emerging technologies to optimize costs, improve efficiency and offer new services to clients.

To bring some perspective to all these fundamental changes, in the uncertain environment following the health crisis, over the past six months we have taken a deep dive with the consultancy firm Altermind, which combines an academic perspective with business insights. In particular, we have relied on the concrete experience of our portfolio companies to try and to understand what will make the resilience of infrastructure over the long-run.

The conclusion of this analysis is straightforward: in the post-Covid-19 world, the digital transformation of infrastructure will be an enabler of both resilience and value creation. Investing in sustainable, resilient and digital infrastructure, as well as actively managing assets in portfolios to adapt them to the increasing challenges of climate change and the emergence of new business models driven by data, is essential.

This has critical consequences for all stakeholders of infrastructure assets, from users to institutional investors. In these critical times, we believe it is of the utmost importance to be able to take a step back, and think through what our options are in the face of these new challenges. We are considering in this study material what is coming next for infrastructure investment and management.

VAUBAN INFRASTRUCTURE PARTNERS

Vauban
115 rue Montmartre,
75002 Paris
www.vauban-ip.com

Vauban Infrastructure Partners, an affiliate of Natixis Investment Managers, is a leading infrastructure asset manager focused on European core infrastructure investments. Based in Paris & Luxembourg, Vauban's team is composed of 40 professionals who have been working together for a decade. Vauban targets predominantly brownfield mid-market sustainable investments pursuing a long-term yield-driven strategy matching the underlying nature of assets. Vauban's approach is based on long-term commitment to all stakeholders' interest through a strong focus on creating sustainable value. Vauban has raised over €4 billion across 6 funds dedicated to core infrastructure from approx. 50 investors within 10 different countries. Vauban has invested in over 50 assets in mobility, energy transition, social & digital infrastructure across 8 different geographies.

Altermind

Altermind
38, avenue Hoche
75008 Paris
www.altermind.com

Altermind is a boutique strategy consultancy. We bring the worlds of business know-how and academia together to help companies prosper. Our global team of business consultants and academic experts provides corporate leaders with tailored, multi-faceted and actionable advice. Altermind's unique methodology gives our clients the edge in today's complex and fast-changing business environment.

TABLE OF CONTENTS
THE ERA OF INFRASTRUCTURE 4.0

6 EXECUTIVE SUMMARY

10 PART I: INFRASTRUCTURE AFTER COVID-19

12 **SECTION 1: After the Covid-19 crisis: Infrastructure in an uncertain world**
12 The world on the eve of the pandemic: A threefold transition
14 A mapping of the world post-Covid-19
20 Infrastructure post-Covid-19: Focus on four assets

26 PART II: THE FUTURE OF INFRASTRUCTURE: INFRASTRUCTURE 4.0

28 **SECTION 2: Infrastructure 4.0: A revolution in progress**
28 What is Infrastructure 4.0?
28 The multiple applications of Infrastructure 4.0
36 Digitalization: A critical challenge for infrastructure

38 **SECTION 3: Infrastructure 4.0: A resilience enabler in the post-Covid-19 world...**
38 What is a resilient Infrastructure?
41 Digitalization: A response to the challenges of resilient infrastructure and cities

46 **SECTION 4:...As well as an avenue for further upside**
46 The strong data potential of infrastructure
51 The infrastructure data value chain
51 The various forms of monetization of data

56 **SECTION 5: Key success factors of Infrastructure 4.0**
56 Implementing data governance within organizations: A challenging project
58 The need for a more flexible contractual and regulatory environment
58 The need for addressing key societal issues

62 PART III: A NEW HORIZON FOR INFRASTRUCTURE STAKEHOLDERS

62 **SECTION 6: Infrastructure 4.0: The reshaping of infrastructure and infrastructure investment**
62 From physical assets to stacked assets
66 From siloed assets to transversal assets and platforms
67 From centralized assets to distributed assets
68 The impacts of Infrastructure 4.0 for infrastructure investors

70 APPENDICES

71 Appendix 1: Biographies of experts
72 Appendix 2: List of participants to the workshops
73 Appendix 3: Glossary
74 Appendix 4: Methodology of the radar graphs
75 Appendix 5: Main bibliographic references

EXECUTIVE SUMMARY

Infrastructures are the set of fundamental facilities and systems serving a country, city, or other area, and encompass basic services such as energy transport and distribution, telco services, transport and mobility, as well as social services (hospitals, prisons, sports arenas, etc.). Like many other businesses, infrastructures have been widely impacted through the past decade by the following **three intertwined transitions:**

⟶ **A societal / demographic transition,** whereby new, digital-native generations, with more fragmented life and job patterns, tend to cluster in denser cities, while the population, overall, is aging. Infrastructures, in particular transport, energy and utilities, have to adapt to these patterns;

⟶ **An environmental transition** whereby concerns on climate change and environmental risks force businesses to adapt their operations to meet carbon-neutral targets and higher environmental standards, under growing political and social pressure. As far as infrastructures are concerned, climate and environmental actions constitute both an opportunity, and, for some sub-asset classes, a problem to be solved;

⟶ **A technological transition,** whereby the increasing reliance on digital technologies, data and AI can be both a facilitator and a question mark for the aforementioned transitions. While infrastructures can be enhanced through data and AI, their business models can also be jeopardized by the "softwarization of hardware" or the emergence of new players.

These transitions had denoted the growing attention of business and political leaders and new time horizons had started to flourish by the end of the 2010s.

Then, the Covid-19 crisis hit. While it is impossible to predict what the outcome of the health and economic crisis will be after the recently announced vaccines are deployed at scale (putting an end, hopefully, to the pandemic), different scenarios could emerge in the coming years. In these scenarios, the threefold transition could be either reversed or accelerated.

A status quo seems, in any event, unlikely. Depending on the importance attached to long-term challenges and on the degree of cooperation between superpowers, the post-Covid-19 world could become a more chaotic place to live in or, on the contrary, more desirable and sustainable.

With respect to infrastructures, the worst scenario –"Chaos"– will prove to be a **critical resilience** test. Not all infrastructures will show the same resilience level in a world where globalization recedes in a dramatic way, environmental goals become a secondary concern, and innovation pace slows down.

At the opposite end of the spectrum, the most desirable scenario –"Green New Deal"– if attained, will reveal an upside potential for infrastructure. Asset classes will benefit in different ways from a world where globalization deepens with more international cooperation and multilateralism. In this scenario, technology and innovation capabilities are harnessed to build a long-term, sustainable future.

While the swiftly changing landscape makes it difficult to make long-term predictions about the future, it is possible, at this stage, to anticipate that infrastructure investors may have to choose between resilience and upside.

However, we argue that digitalization of infrastructure–a transformation which is in progress–**is an agent of both resilience and upside in an uncertain world.**

The digitalization of infrastructure can be defined as the incorporation into infrastructure of the 4th industrial revolution, characterized by the massive use of digital technologies, smart systems, physical assets, people and businesses altogether into an integrated data-driven ecosystem.

Digital technologies, data and AI are pervasive and, if handled correctly, with the help of appropriate governance, skills and ethics, can:

• Improve resilience by making the operation of assets more efficient and secure, and by helping to adapt to the unknown;

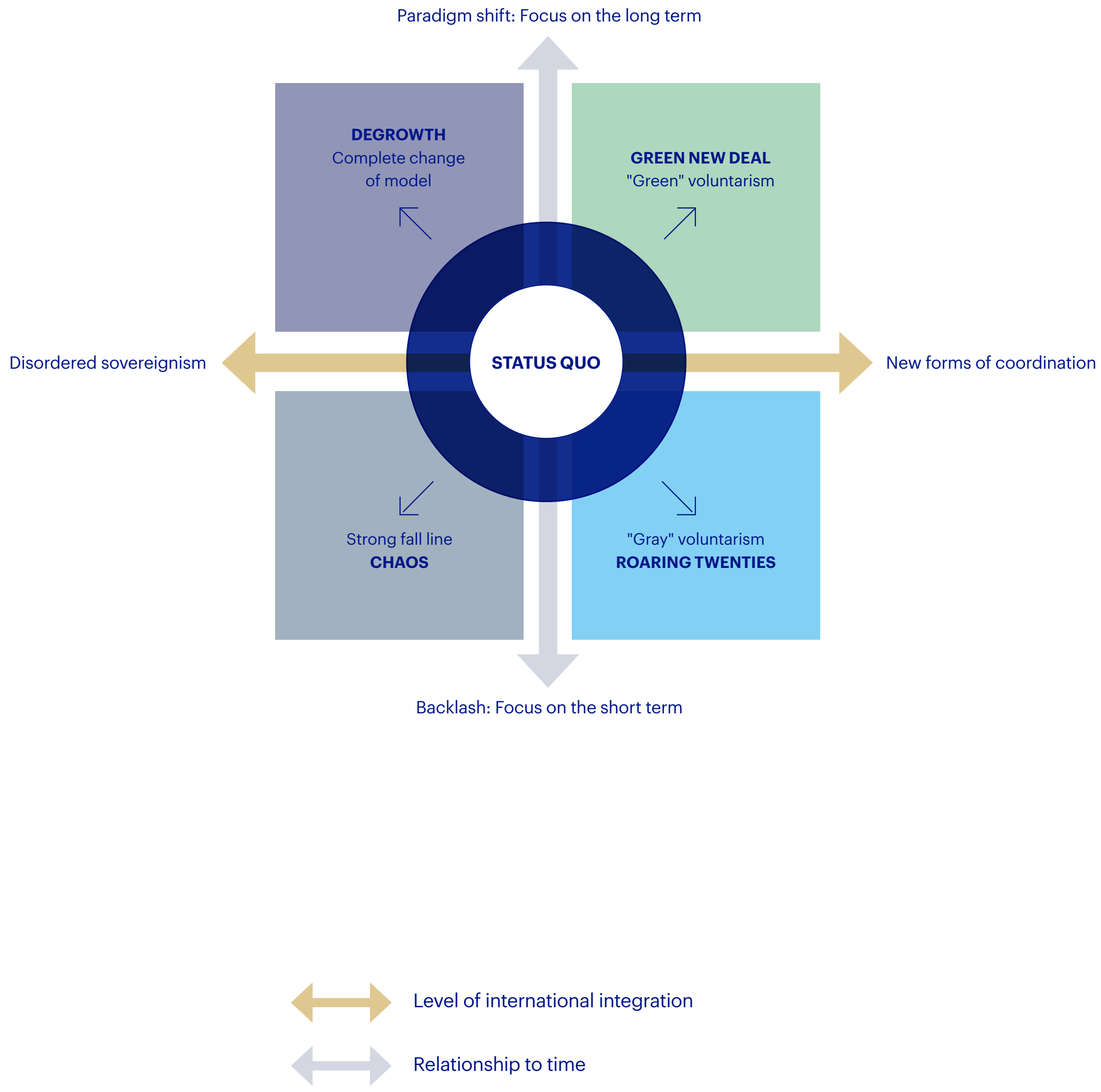
•Maximize upside by opening new avenues for growth, based on data-driven business models.

⟶

INFRASTRUCTURES HAVE BEEN HIT BY A SOCIETAL, ENVIRONMENTAL AND TECHNOLOGICAL TRANSITION

MAPPING OF THE WORLD POST-COVID-19

Source: Altermind



Hence, digitalization provides an opportunity for infrastructure investors to be exposed to the best of both worlds: downside protection and upside potential. However, a new perspective on how to build, deploy and operate these assets is required.

In the Infrastructure 4.0 era, infrastructures are not only physical, but also integrate advanced communication and data processing technology, which make them more adaptable to different environments and help to deliver more effective services.

Digitalization has started to reshape infrastructure:

⟼ **From physical assets to stacked assets:** "smart" infrastructures are composed of several layers, from sensors to applications and the boundaries between hardware and software are blurring. In this context, infrastructure managers should follow a "holistic" approach, taking into account, from the outset of any project, not only the physical characteristics of infrastructure assets but also the technology embedded in it, with a focus on its applications and the services delivered to users. This is the case, for instance, for street furniture (smart lighting, traffic lights, traffic signs, bus shelters, etc.);

⟼ **From sectoral assets** to desiloed assets: infrastructure assets should now be conceived as **transversal assets, requiring the cooperation of various stakeholders.** This is particularly true in an urban environment, where platforms are key drivers of smart and sustainable cities. Parkings illustrate this trend well, where more and more services (EV charging, logistics, etc.) are offered;

⟼ **From centralized assets to distributed assets:** digitalization creates new opportunities to better address clients' needs, through light and distributed assets instead of heavy and centralized assets. This can already be observed today in the electricity market (with the meter management systems and micro-grids) and in the telco sector.

The digitalization of infrastructure leads to profound changes in the way infrastructure assets should be designed and operated. It also has major impacts on investment strategies, in respect of:

⟼ **The selection of investment opportunities,** which should combine a "least regret strategy" focused on the most resilient assets, and a "brave new world strategy" relying on assets offering the highest long-term value-creation potential;

⟼ **Transaction structuring,** which should better take into account the polymorphic revenues, risks and time horizons provided by the digitalization of infrastructures;

⟼ **Investment perimeter,** which should entitle investors to move up the value chain to capture some of the added value created by data;

⟼ **The management of assets,** which should contribute to adapting and upgrading existing infrastructure while controlling the risks arising from digitalization.

METHODOLOGY OF THE STUDY

Reflecting Altermind's DNA, this study combines academic expertise with business insights, relying on the review of the existing literature and the outcome of thematic workshops organized with academic experts, investors and managers of Vauban Infrastructure Partners' portfolio. Altermind has mobilized its network of academics and experts in order to bring perspective to this study with a cross-sector approach. They presented their views and interacted with professionals during four workshops dedicated to:

- The analysis of the impacts of the crisis on infrastructure, with Patrice Geoffron (Paris Dauphine–PSL);

- The state of play of the digitalization of infrastructure, with Guillaume Gazaignes (Energy and Transportation Expert);

- Smart cities as resilient cities, with Nicos Komninos and Christina Kakderi (Aristotle University of Thessaloniki);

- The value and governance of data, with Henri Isaac (Paris Dauphine –PSL) and Adrien Basdevant (Lawyer);

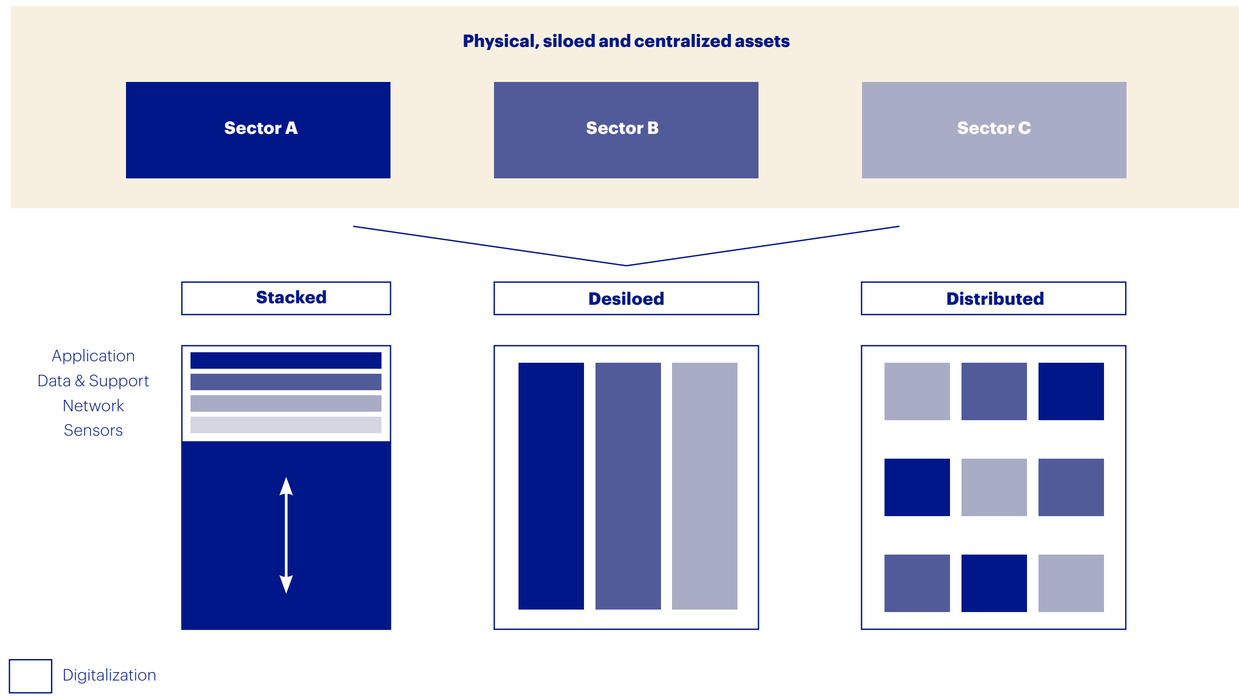
- The biographies of the experts are presented in Appendix 1 and the participants to all workshops are listed in Appendix 2.

⟶

DIGITALIZATION OF INFRASTRUCTURES IS AN AGENT OF BOTH RESILIENCE AND UPSIDE IN AN UNCERTAIN WORLD

DIGITAL INFRASTRUCTURE

Source: Altermind



INFRASTRUCTURE 4.0: INVESTMENT STRATEGIES IN THE POST-COVID-19 WORLD

Source: Altermind

	INFRASTRUCTURE PRE-COVID-19	INFRASTRUCTURE 4.0 IN A POST-COVID-19 WORLD
PREFERRED ASSETS	Long-term, stable, predictable cash-flows…	… with proven resilience and significant upside potential
TRANSACTION STRUCTURING	Project, non-recourse finance…	… toward hybrid financing (project, corporate)
INVESTMENT PERIMETER	Physical asset…	… and IP, talents
ASSET MANAGEMENT	Focus on maintenance	… and innovation

PART I: INFRASTRUCTURE AFTER COVID-19

The infrastructure sector will be deeply impacted by the Covid-19 crisis. The consequences will vary depending on the scenario emerging from the crisis, which is still uncertain. In this context, each infrastructure asset should be assessed according to its resilience and upside potential.

AFTER THE COVID-19 CRISIS: INFRASTRUCTURE IN AN UNCERTAIN WORLD

THE WORLD ON THE EVE OF THE PANDEMIC: A THREEFOLD TRANSITION

Before the pandemic, three intertwined transitions were effective (Figure 1).

◇ The environmental transition
With the rise of climate concerns, the growing awareness of biodiversity, and air quality issues, expectations for an environmental transition have increased.
For the first time in the Global Risks Report 2020 of the World Economic Forum (WEF)[1], **the top five most global risks** were all environmental related: extreme weather events; failure of climate change mitigation and proper reaction by governments and businesses; human-made environmental damages and disasters (including environmental crimes such as oil spills); major biodiversity losses and the collapse of the ecosystem; major natural disasters such as earthquakes, tsunamis, volcanic eruptions, etc.[2]. As a result, citizens have expected **more eco-friendly public policies,** with a transition from an energy system that is essentially based on the use of fossil, depletable and greenhouse gas-emitting energies (oil, coal and gas) to an energy mix that promotes the use of renewable energies (solar energy, wind energy, geothermal energy, hydropower, etc.) and energy efficiency.

◇ The technological transition
The second transition has been a technological one, characterized by the growing importance of data and artificial intelligence (AI) as well as the emergence of new business models around platforms. Before the Covid-19 crisis, it was expected that in 2025, 60% of data would be integrated in the public cloud, while 30% would be "real time" and the turnover of AI-related activities would be 15 times higher[3]. The cloud, Robotic Process Automation (RPA), Internet of Things (IoT) and augmented reality have already started to deeply impact many economic fields. The deployment of 5G is set to accelerate advances in smart vehicles, smart manufacturing, and numerous other IoT technologies.

KEY TAKEAWAYS

Covid-19 hit at a time when a threefold transition was in play: environmental, technological and societal. Considering this threefold transition, the Covid-19 crisis may have two effects: it will either reverse or accelerate these trends.
From this perspective, depending on the weight given to long-term issues and the future of globalization, four possible scenarios could emerge from the crisis:

The Green New Deal scenario is the positive outlook, with a broad consensus on ecology and technological innovations;

The Roaring Twenties scenario is characterized by a short-term economic recovery reducing unemployment and driving vulnerable sectors, with low consideration for the environment;

The Degrowth scenario promotes ecological and sober behaviors to foster a low-carbon and frugal model;

The Chaos scenario world is based on carbon intensive models, national retreat and low technology.

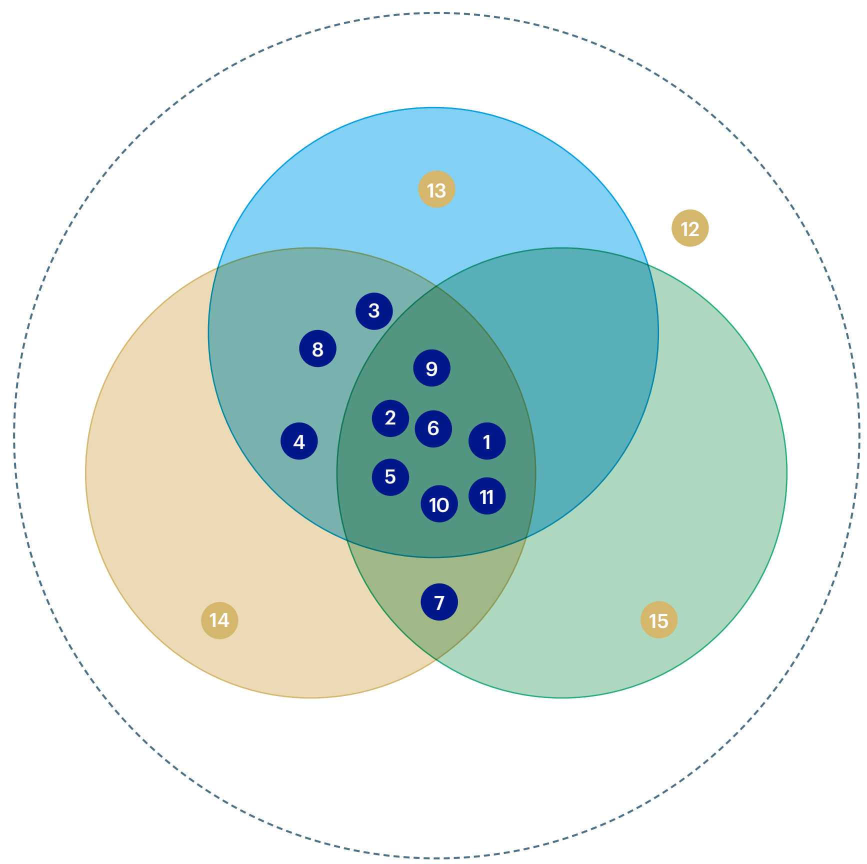
The future of infrastructure will be deeply impacted depending on the prevailing scenario. Infrastructure assets should tend toward resilience in the worst scenario and upside potential in the most favorable one.

⟶

ON THE EVE OF THE COVID-19 CRISIS, A WORLD SHAPED BY THREE INTERTWINED TRANSITIONS

(1)World Economic Forum (2020), Global Risks Report 2020
(2)World Economic Forum (2020), Burning Planet: Climate Fires and Political Flame Wars Rage
(3)Data Age 2025, The Digitalization of the World from Edge to Core

FIGURE 1
THE THREE TRANSITIONS SHAPING THE WORLD BEFORE COVID-19
Source: Altermind



MEGATRENDS

1 Digitalization of usage
2 AI-related breakthroughs
3 Personal data sensitivity
4 Aging population
5 Territorial divide
6 Lifelong fragmentation
7 Circular economy
8 Future of work
9 Carbon neutrality/impact
10 Restraint
11 Search for meaning
12 Regulatory environment (France/EU)
13 Other technological issues: medical research, etc.
14 Other societal issues: gender parity, etc.
15 Other environmental issues: biodiversity, air quality, etc.

- Societal transition
- Technological transition
- Environmental transition
- Economic and political context

◇ The societal transition

The third transition covers three main sets of issues which shape society: spatial (urbanization, territorial divides), social (inequalities, middle class decline) and generational (population aging, aspirations and behaviors specific to "generation Z").

New digital-native generations, with different life and job patterns, have tended to cluster in larger and denser cities, alongside an aging population: two-thirds of the global population will live in cities in 2050 according to pre-crisis forecasts[4]. New generations have also started to ask for more "restrained practices" and environment-friendly conditions relating to their work and living standards.

Finally, the world has become hyper-connected: 3.9 billion people are using e-mails to connect in 2019, with a projection of 4.3 billion in 2023[5]. Still, the lockdown due to the Covid-19 crisis has highlighted the impact of the inequalities caused by this technological changeover.

These three transitions are interdependent: they can either have underpinning roles (such as aspirations of new generations echoing environmental concerns) or conflicting roles (such as the ecological impacts of some new technologies).

A MAPPING OF THE WORLD POST-COVID-19

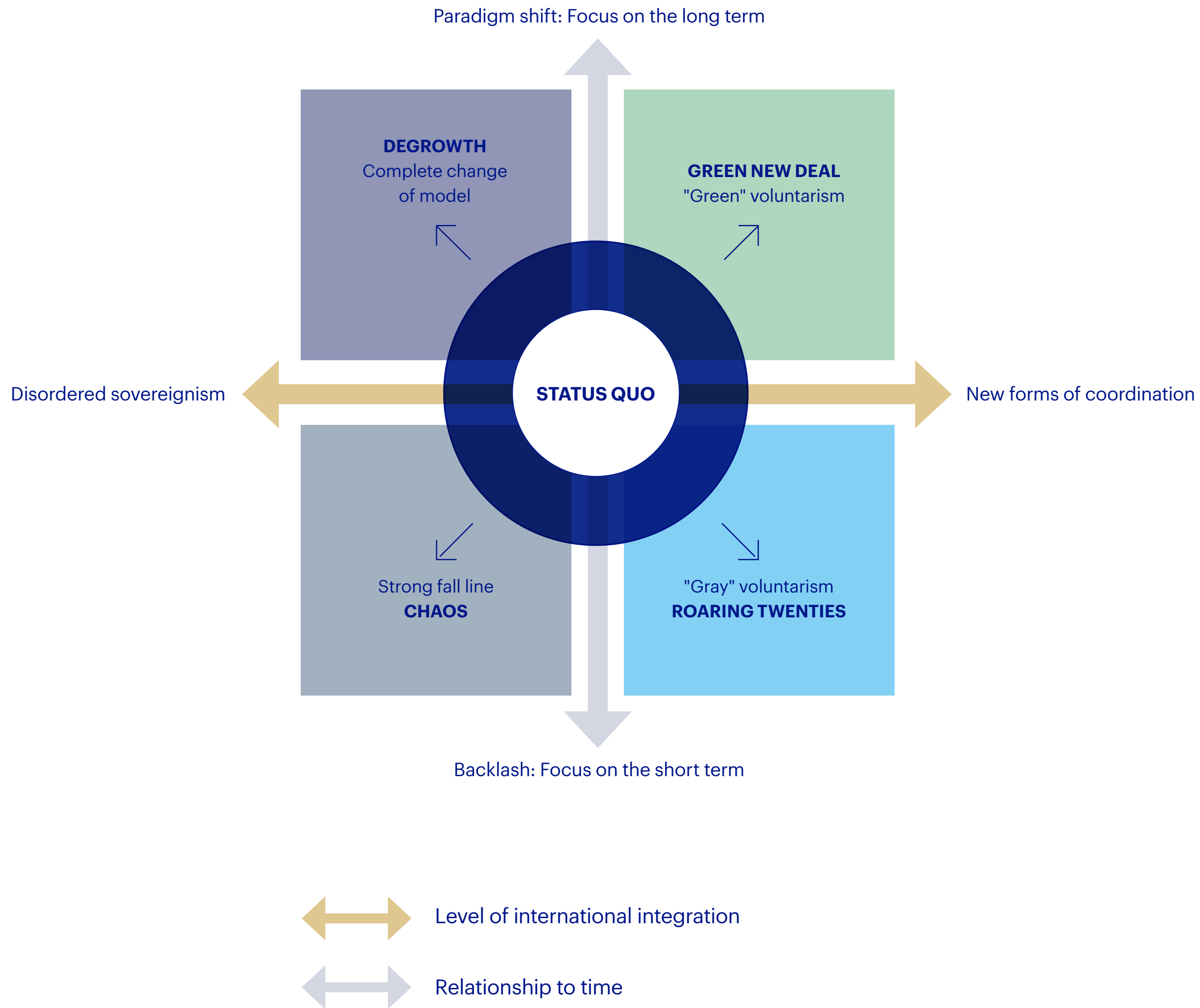
The Covid-19 crisis is unique because of its global reach, which can be explained by the worldwide virus propagation and the interdependencies resulting from four decades of globalization. There is today a unique storm brewing in the global economy and its long-term effects are yet to be fully assessed. Even though vaccines have been announced for the beginning of 2021, there is every reason to believe that the crisis will have, at least to some extent, lasting impacts. This contextual uncertainty poses an unprecedented challenge to governments, industries and investors alike, which need to propose an ambitious –yet effective– response.

The post-crisis period will be determined by short-term health and economic imperatives. Fiscal policies are pressured into limiting the negative impact of the crisis on the national economy (rising unemployment, decreasing consumption, etc.) and supporting struggling enterprises. The European Union agreed on a €750 billion (grants and loans) recovery plan in July 2020. The German and the French recovery plans respectively reach €130 billion and €100 billion. The recovery will take time, especially as a second wave of the pandemic has hit the world in autumn 2020.
Forecasting the consequences of the crisis for the next decade is even more uncertain. In order to assess these impacts, a broad analytical framework has been designed to map possible scenarios after the crisis. This matrix is built around two axis, and results

THE CRISIS HAS TRIGGERED AN UNPRECEDENTED SOCIO-ECONOMIC SHOCK, WITH UNCERTAIN LONG-TERM EFFECTS

[4] United Nations, Department of Economic and Social Affairs, Population Dynamics (2018), 2018 Revision of World Urbanization Prospects
[5] The Radicati Group, Email statistics report, 2019-2023

FIGURE 2
MAPPING OF THE WORLD POST-COVID-19
Source: Altermind



in four potential scenarios post-Covid-19, which will affect to varying degrees the way the aforementioned threefold transition unfolds (Figure 2).

◇ Two key determinants: the relationship to time and the future of globalization

The vertical axis of the matrix refers to the **relationship to time.** In the present context, short-term or long-term concerns may prevail in public policy decisions, business strategies, citizens' behaviors and expectations. The central variable is the way all stakeholders will address future risks (health, social or environmental crises) and trade those future risks against immediate concerns (dealing with the pandemic and designing stimulus packages). As a result, this axis will determine if the world post-Covid-19 will **be future- or present-focused.**

This shall affect key time-sensitive factors such as ecological and restrained practices, appeal for a low-carbon development, long-term investments in infrastructure, or importance given to ethical issues, etc. For instance, renewable energies have a strong potential and are economically viable in Eastern European countries such as Poland, but these countries still heavily rely on carbon-intensive energies at the moment.

The horizontal axis is related to the fate of the "international liberal order," which can be defined schematically by the following three features:

- The expansion or contraction of **liberal democracy**, based on people's participation and the protection of citizens' rights and freedoms;
- The expansion or contraction of **economic and financial globalization,** marked by the movement of people (migration flows, tourism), goods (trade, tourism), services (transport), and capital (direct investment flows, financial markets);
- The expansion or contraction of **multilateralism and inter-state cooperation** within various bodies (UN, G8, G20, WTO, COP, WHO, etc.).

This international liberal order has been challenged in recent years by various phenomena among which the advent of the "illiberal democracies," the American political cycle marked by the questioning of multilateralism or the anti-globalization activism. The crisis could emphasize these challenges or, on the contrary, lead to a strengthening of the "international liberal order."

As a result, this axis will determine if the world post-Covid-19 will lean toward either a fragmented "sovereignism" with societies choosing isolationist strategies or a renewed international integration, where new forms of coordination and solidarity are valued. This will mainly depend on whether collective objectives are prioritized in public policy decisions.

◇ Four possible scenarios

Considering the magnitude of the crisis and its multiple economic, financial, and societal impacts, a status quo seems unlikely. Depending on the weight given to long-term issues and to the future of globalization, the world could take the form of four main "archetypes."

In the Green New Deal scenario, the shock of the Covid-19 crisis and the importance of global risks (health as well as environmental) encourage the major players of the international community to address short and long-term issues alike.

There is a broad consensus to design long-term solutions and the economy is increasingly turning toward green growth, with the implementation of "green" new deals: to exit from the crisis, public policies prioritize and optimize **"co-benefits" (i.e. economic, environmental and health impacts) at national, regional and global levels.** The world shifts toward a "regulated globaliza-

THE FUTURE OF THE WORLD WILL DEPEND ON THE WEIGHT GIVEN TO LONG-TERM CONCERNS AND THE LEVEL OF INTERNATIONAL INTEGRATION

tion" with new standards on international trade and a green model in line with the Paris Agreement. This scenario requires a very ambitious effort to mobilize all innovations for low-carbon technologies.
Digital and smart systems are crucial assets in this scenario. Infrastructure 4.0, based on the most recent technologies and data-driven models, will make assets more resilient and forward-looking. In this context, the Green New Deal is an opportunity to harness the power of data in order to create more efficient infrastructure (smart grids, faster broadband, stronger bridges, safer highways, etc.).

Finally, **inclusiveness** is a key aspect of the Green New Deal. With this scenario comes deep transformation and significant wealth transfer. The social protection system and companies have a crucial role to address societal challenges, and define a new vision to "build back better."

In the Roaring Twenties scenario, a broad consensus is shaped to revive the economy and reduce unemployment in the short-run and to rely on multilateralism and international cooperation.

This type of recovery promotes the urgency of stimulating the global economy, through a rapid return to old consumption patterns, safeguarding legacy businesses (automotive, air transport, tourism, etc.) and investment in mature industries. As a result, the economy will recover rapidly over the next few years through incremental innovation, but with a high risk of worsening the current environmental debt, increasing inequality and collective costs over time.

In the Degrowth scenario, the growth model pre-Covid-19 based on carbon energies and globalization is questioned in order to cope with the ecological crisis.
Based on a collective preference for resilience and restraint, priority is given to the management of long-term issues in a so-called "sovereign" deglobalized space (at national or regional scale). The world shifts to a **less carbon-intensive and low-tech model:** new consumption and production models are favored, with the rise of restrained practices, a new agricultural model, the priority given to medium-sized cities, shorter production and logistics chains, etc.

However, while OECD countries maintain living standards at an acceptable level, the diffusion of progress to the more advanced developing countries is slowed-down due to the lack of broad cooperation, increasing the exposure to risks of defaults (e.g. oil-exporting countries).

In the Chaos scenario, the crisis leads to a regional-national retreat combined with **short-term policies, increasing the exposure to new shocks,** such as financial, health, social and environmental crises. In this scenario, governments refocus on their direct short-term interests and reinforce their own tropisms and priorities. In a context of economic slowdown, there is less innovation. The choice is made to promote low-cost solutions, which will favor fossil fuels in the short term. In the same vein, the crisis may affect the development of renewable energies, with growing uncertainties and financing difficulties.

→

FOUR SCENARIOS MAY ARISE FROM THE CRISIS: THE GREEN NEW DEAL, THE ROARING TWENTIES, DEGROWTH AND CHAOS

EXPERT POSITION 1 / **Mounir Corm Deputy CEO of Vauban IP**

"As an investment fund committed to sustainable development, we strongly believe this Green New Deal scenario is the most desirable from a collective standpoint and we are determining our investment strategy accordingly.

We are shaping our contribution with this objective in mind: by betting on the long term to invest in infrastructures participating to the building of new shared futures: roads, schools, hospitals, digital networks, energy systems, urban environments, etc.

However, the challenges behind this scenario should not be underestimated: sustainable development requires a lot of financial resources and comes with major societal challenges, such as stranded assets or jobs replaced by digital technologies."

VAUBAN
INFRASTRUCTURE PARTNERS

INFRASTRUCTURE POST-COVID-19: FOCUS ON FOUR ASSETS

The crisis will have substantial long-term impacts on the infrastructure sector.

It is already quite obvious that, whatever the prevailing scenario, the crisis will have structurally modified **the demand for certain services and introduced structural substitutions** (e.g. long-distance transportation with remote digital practices, substitutions within mobility modes in urban areas, etc.), which will have an impact on the related infrastructures.

The way infrastructure will answer demand will depend on key factors described above such as **digitalization, technological innovations, government funding, international cooperation, etc.**

In this uncertain context, two main criteria become critical for infrastructure: resilience (understood as the capacity to resist and absorb shocks) and value creation.
Infrastructure assets may display **heterogeneous resilience and value-creation potential,** depending on the prevailing scenario.

Within each "vertical" of the infrastructure sector (telco, energy, transport and mobility, social infrastructure), the situation may vary considerably. For instance, while the Green New Deal scenario will favor low-carbon innovations and solutions, with positive impacts for renewables or clean mobility it will also create "stranded assets" in carbon-intensive sub-sectors (oil and gas, transport, etc.).
The resilience and development potential of infrastructure assets are represented herefater through **"radar graphs,"** designed according to a methodology consistent with the threefold transition and the mapping of the world post-Covid-19, further described in Appendix 4.
This methodology has been applied to four specific assets in each of the main "verticals" of the infrastructure sector: **5G, smart grids, urban public transportation and health infrastructure.**

Although based, by definition, on simplified assumptions, this approach provides a general perspective of the future of infrastructure in the different scenarios after the Covid-19 crisis and helps **to benchmark the dynamics of distinct infrastructure sectors.**

◇ Radar Graph–5G

5G is the next generation of wireless connectivity, which enables faster download and upload, lower latency, wider coverage, and more stable connections thanks to IoT devices. 5G is a clear paradigm shift: it will allow performance up to ten times higher than 4G, divide response times by ten and stimulate a huge increase in connection density due to the rise of connected objects.
The Green New Deal scenario is beneficial to the development of 5G because of **favorable high-tech environment, growing digital usage and the ambition to reduce the digital divide.** 5G is seen as a more efficient technology (predicted to be 20 times faster by 2030) and a way to promote new digital usage to replace old carbon-intensive practices, particularly in the B2B business.

In the Degrowth scenario, the potential development of 5G is very low (even lower than in the Chaos scenario), in a context characterized by restrained and frugal practices. There is a **stagnation in basic connectivity and a crisis in the digital sector.** In this scenario, innovation is either slowing down or low-tech, and society is **reluctant to take up new technologies such as 5G,** considering it would encourage new useless digital uses and hence more energy consumption.

The Roaring Twenties scenario offers wide opportunities for 5G, since the **increased need for connectivity** (teleworking, distance learning, streaming) intensifies users' digital practices and behaviors. Deepening globalization is also favorable to 5G, as it allows technology transfer from Asia and new generations of advanced applications. It also fosters business innovation and stimulates economic growth, which are important factors in the deployment of 5G.

In the Chaos scenario, geopolitical tensions (in particular with China, as Huawei has been banished from multiple countries due to fear of cyber-attacks and spying) contribute to destabilizing the telco market. The implementation of 5G is consequently delayed, as governments and private investors face drastic financial constraints.

◇ Radar graph 2–Smart Grids

Smart grids represent electricity networks integrating digital and advanced technologies to monitor and manage the distribution of power from different generation sources to final consumers. They constitute **keystones in the energy transition** as they facilitate the integration of renewable energies into the power grid and key substitutions (from thermal to electric vehicles). As consumers have a key role to play in the electric system equilibrium, social behaviors toward high-tech systems and ecological concerns are crucial factors.

→

IN AN UNCERTAIN WORLD, INFRASTRUCTURE SHOULD TEND TOWARD RESILIENCE IN THE WORST SCENARIO AND VALUE CREATION IN THE MOST FAVORABLE

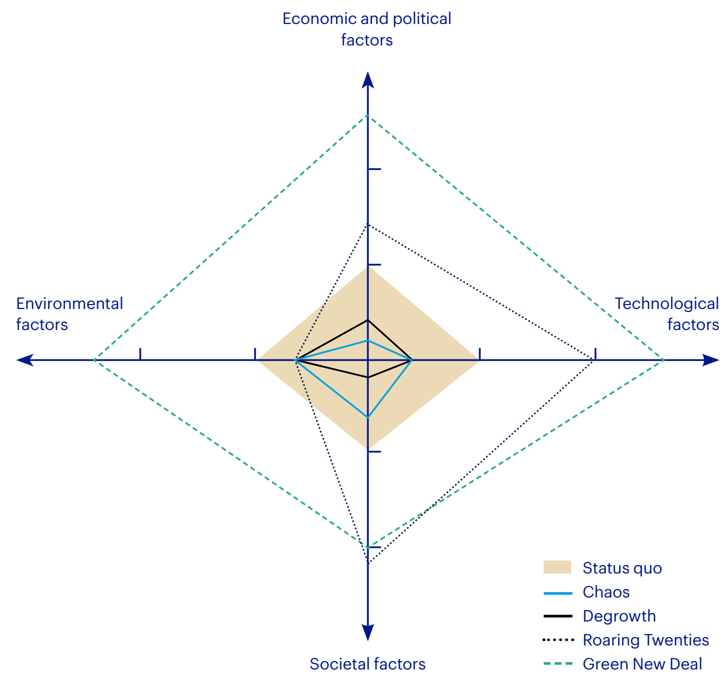
The Green New Deal scenario presents the most important potential for the development of smart grids. In this scenario, smart grids will further participate in the energy transition by integrating all intermittent renewable energies through a continuous adaptation of the network and an increase in its capacities. **Digitalization and advances in energy** storage will make the network more resilient.

In the Degrowth scenario, environmental factors are favorable for smart grids but the reluctance toward investment in technology restrains its deployment. Although renewable energies are deployed in a decentralized scheme (photovoltaic, bioenergy) and play a major role for a decarbonized supply, low growth and restraint have a negative impact on smart grids and smart cities as **investments lag behind.** Indeed, considering the current state of smart grids, an efficient implementation still requires significant public and private investments.

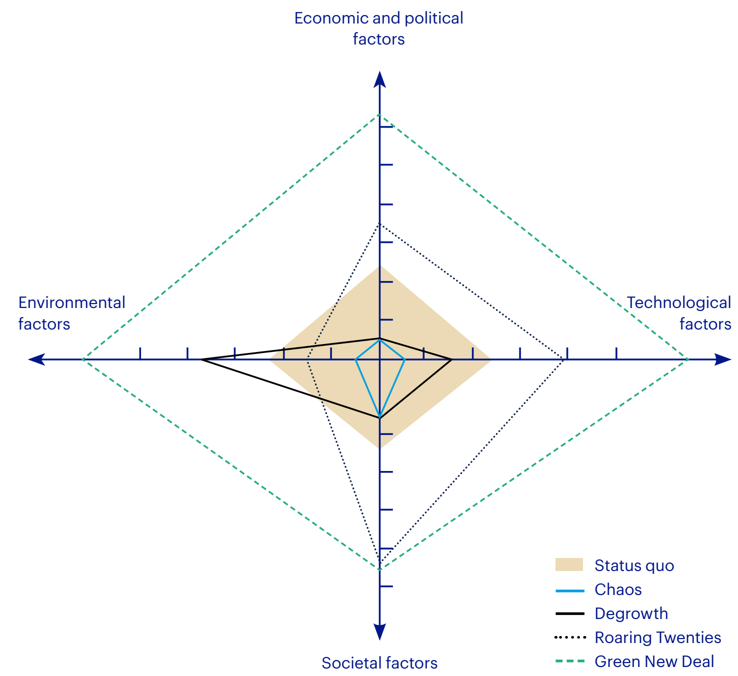
The Roaring Twenties ambition puts aside sustainable development and energy transition. In this scenario, smart grids are mainly driven by technological and societal factors (urbanization, digital usage) because environmental concerns are not a priority.

The Chaos scenario is unfavorable to smart grids as old consumption behaviors are preferred. While smart grids essentially rely only on renewable energy within a sustainable world, fossil-fuel still remains a commonly used source of electricity in this scenario. In brief, **the lack of economic incentive** has a strong negative impact on the spread of smart grid usage. Also, risks regarding data security and privacy (cyber-attacks) raise a reluctance toward smart grids.

In any case, the potential development of smart grids relies on a **wider smart ecosystem (smart cities):** smart grids technologies offer innovative opportunities for collaboration between electricity, gas, heat and telecommunications networks. Opportunities for increased collaboration with the telco infrastructure and industries will abound. However, the development of smart grids still requires substantial investment.



RADAR GRAPH 1
5G



RADAR GRAPH 2
SMART GRIDS

◇ Radar Graph–Urban Public Transportation (UPT)

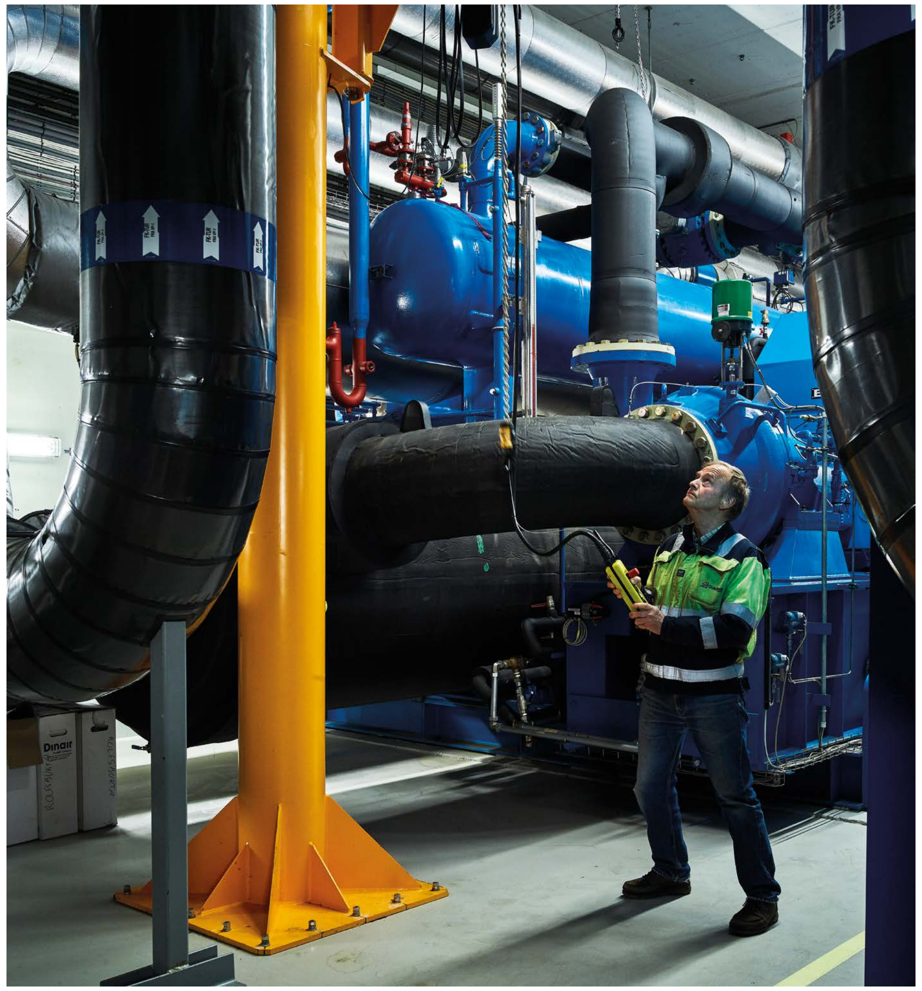
The Covid-19 crisis has been characterized by a radical freeze in mobility, which has affected the automotive and transport sectors. Mobility behaviors have changed significantly, as many people have started to work from home and others are still avoiding public transportation due to health concerns. However, in the longer term, UPT will probably remain one of the backbones of cities, along different lines depending on the prevailing scenario.

In the Green New Deal scenario, technological and environmental factors have a very strong impact on urban public transportation. Societies are adopting more restrained and greener ways of living, relying on innovation. This favors **new mobility solutions** (electric mobility, autonomous vehicles, MaaS, free-floating mobility, etc.). In this scenario, individual cars do not disappear, as electric and autonomous cars emerge. It favors public transportation, provided investment is made. Also, the increase in digital uses (teleworking, home delivery) reduces congestion and promotes a reorganization of territories.

In the Degrowth scenario, the potential for development is high for UPT. Environmental and societal factors are key: although demand is negatively impacted by restrained behaviors, they favor UPT as a cleaner transportation mode than individual cars, in a context where innovation declines. Simultaneously, the slowdown of urbanization is linked to a shared desire by citizens to return to rurality, provoking a **reallocation between urban and interurban transport.**

In the Roaring Twenties scenario, **intensive mobility** goes together with an **increasing urbanization** due to the focus on short-term growth. This is favorable to UPT. However, individual cars remain the leading transport mode and the energy transition slows down. The indifference toward climate and environmental issues constitutes an obstacle to cleaner mobility solutions.

The Chaos scenario does not favor UPT. As there is limited interest in ecology, the population appeals for an **old and carbon-intensive mobility model,** essentially based on fossil-fueled individual cars and the pursuit of urbanization.
In any scenario, Covid-19 will have a lasting impact on public transport. **Safety requirements** will redefine the structure of public transport: a "safe" trip in a bus is not only about crashes or crime any more, but also hygiene and health. Digitalization and technological factors will disrupt the sector by promoting a new range of measures to be deployed in shared vehicles or before entering a terminal: improved cleaning processes (thermal scans before boarding, self-cleaning vehicles), cashless systems, etc.



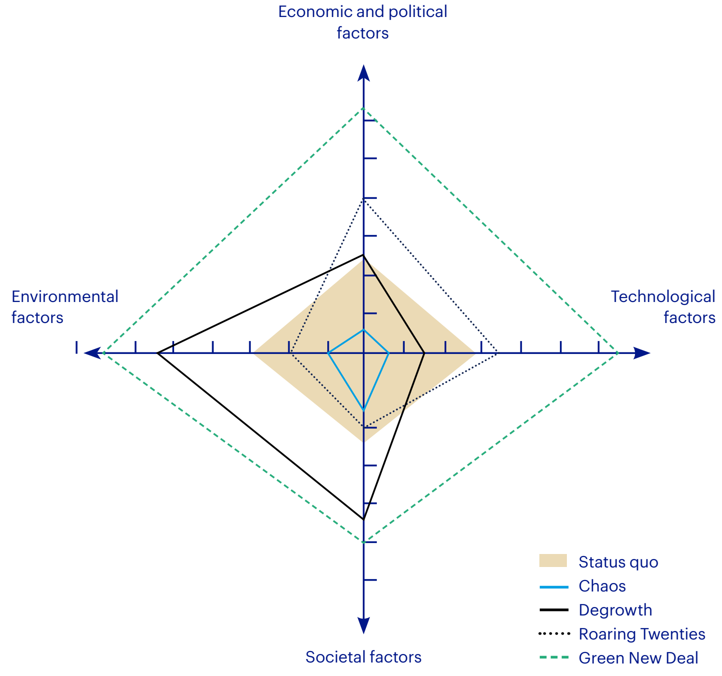
◇ Radar graph 4–Health Infrastructure

The health infrastructure sector appears as the most stable sector in the various scenarios. The most favorable scenario to the sector is the Green New Deal: technological factors have a strong impact and enable more responsive and resilient health systems. In this context, public investment will have a major impact and support technological innovation as well as the collaboration between researchers and various industries. This scenario allows a **deep modernization of health infrastructures, with an accelerated digitalization and a growing demand for high-quality assets.** Digitalization has the potential to disrupt the health infrastructure sector: digital health technologies can improve access to health services, increase the quality of care and enhance the efficiency of health systems, through epidemic forecasting and decision-making.

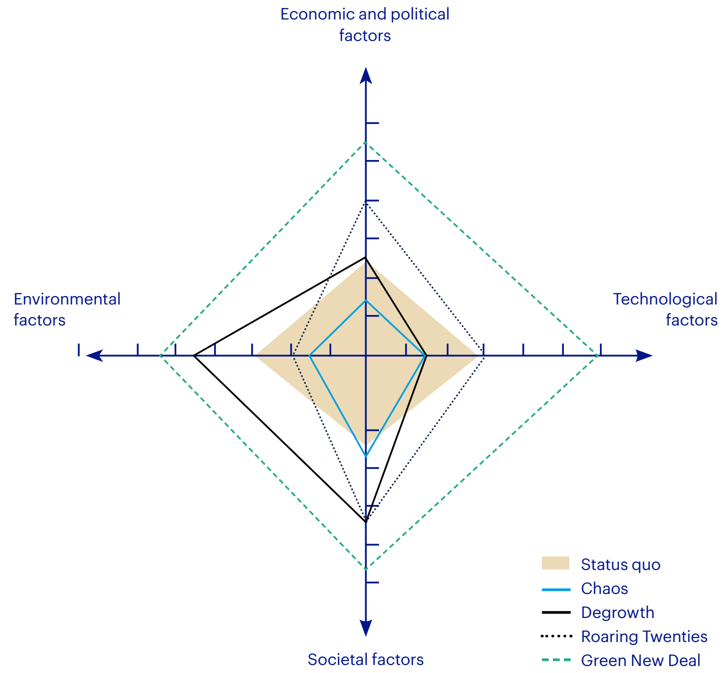
In the Degrowth scenario, **concerns related to the health and the ecological crises** support the health infrastructure sector. Decarbonization promotes higher-quality and efficiency buildings. This scenario is characterized by financial constraints faced by public clients, impacting welfare policies, but creating a search for innovative financial design. **The desire to return to rurality** creates a drive to redeploy assets / buildings and reduces the digital divide.

In the Roaring Twenties scenario, technology is a key factor for health infrastructure assets. In the long term, some asset classes (retirement homes, etc.) may be negatively impacted by **deteriorating environmental conditions** such as air quality.

Chaos is the least favorable scenario for the health infrastructure sector. This scenario shows a **clear retreat from the welfare state.**



RADAR GRAPH 3
URBAN PUBLIC TRANSPORTATION



RADAR GRAPH 4
HEALTH INFRASTRUCTURE

CASE STUDY 1 / METRO MÁLAGA, DIGITALIZATION AND THE CRISIS

Metro Málaga is the light rail network of Málaga, which consists of two lines currently in service. The network is managed by the concessionary company of the Junta de Andalucía.

The digital transformation of Metro Málaga started in 2014. It has improved efficiency, through the optimization of its internal processes, and obtained an improvement in the overall customer experience, based on new services.

Among key current projects (Figure 3), the "Goals systems" (2019-2020) is a powerful digital tool for management and employees to optimize operations (control processes, rolling stock, staff timetable, export data to payroll, etc.): benefits are expected in 2021 but the integration of multiple providers, technologies and data remains challenging.

In the context of the Covid-19 crisis, Fernando Rozano Luis, director general of Metro Málaga, explains that:

"The key challenge was to maintain the service with only 25% of staff. 95% of traffic was lost during lockdown and we expect only 50% of traffic this year. To face the health crisis, new measures have been taken: masks are compulsory, train doors open at every stop, hydroalcoholic solutions are available. While it was not initially intended for this purpose, digitalization can be an efficient tool to spread safe health practices: for instance, the next stage of our transformation is allowing credit cards to pay directly, which will reduce human interactions and potential contamination."

FIGURE 3
SELECTION OF PROJECTS FROM THE DIGITAL TRANSFORMATION PROGRAM OF METRO MÁLAGA

Source: Metro Málaga

ITEM	DESCRIPTION	KEY BENEFITS
Goals Systems (2019-2020)	• Design and development of resource optimization systems for the transport sector. Málaga Metro created a GRM (Goal Rail Metro) allowing an optimal planning of timetables, rolling stock and crews in railway transport.	• Optimizes services offered and their quality: fits services offered on demand. • Reduces non-productive use of trains. • Optimizes services offered to passengers: ensures compliance with commercial timetables. • Optimizes strategic decision-making: simulates new scenarios, new track sections or services, etc.
APP & Ticketing Web Service (2018-2019)	• Design and development of the new APP, which provides helpful tools and improves customer experience. • Establish a web service (communication between app, bank, and ticketing system) for the online ticket top up and balance check.	• Top up online tickets, check the existing balance for personal cards. • Real-time schedule and waiting times of favorite stations. • Trip planner linked to Google Transit. • New "virtual screen," using the same software of the traveler information system of stations, PCC can send important messages to customers.
Web List Ticketing System (2019)	Our ticketing provider, INDRA, developed a more complete "action list," which includes online top up (white list) and balance corrections (gray list).	• Improvement to the customer service experience. • Reduction in issue-resolution times, less paper and more efficient processes.

PART II: THE FUTURE OF INFRASTRUCTURE: INFRASTRUCTURE 4.0

The Covid-19 pandemic has accelerated the need for modern digital infrastructure in the short run, driven by the constraints of lockdown and health-safety measures. However, the need for digitalization will survive the crisis in all infrastructure sectors. Indeed, whatever scenario emerges from the crisis, digitalization will be a strong factor of resilience and of value creation, provided it is handled correctly.

KEY TAKEAWAYS

Infrastructure 4.0 seeks to improve the adoption of emerging technologies of the 4th industrial revolution across all infrastructure lifecycle stages (planning, design, construction, operation, service) by introducing new digital processes.

Considering the significant gaps in the adoption of technology and the use of data in infrastructure decision-making, the digitalization of the infrastructure sector must leverage key enablers: innovation, cross-industry collaboration, organizational changes, private and public investment.

The adoption of Infrastructure 4.0 will be key to ensuring resilience and maximizing upside in an uncertain post-Covid-19 world.

INFRASTRUCTURE 4.0: A REVOLUTION IN PROGRESS

WHAT IS INFRASTRUCTURE 4.0?

The end of the 18th and the 20th centuries witnessed three so-called "industrial revolutions": mechanization; electricity, oil and gas; electronics, telecommunications and computers.

The 21st century is marked by a 4th industrial revolution, which is characterized by the ubiquity and pervasiveness of digital and data–through such technologies as IoT, big data, AI, augmented reality, blockchain, drones, etc.– in production processes, organizations, machines and collaborative tools. The 4th industrial revolution connects **machines, people, and physical assets to an integrated digital ecosystem** in order to improve productivity and develop new uses (Figure 4).[6]
The technologies forming part of this revolution are in the process of being applied to all sectors of industry, including infrastructure. Thus, the digital transformation of infrastructure can be described as the application of the 4th industrial revolution to the infrastructure sector: "Infrastructure 4.0."
Infrastructure 4.0 can range from building more resilient bridges by using advanced materials and big data, to creating entire smart cities where buildings, traffic lights, and roads communicate directly with each other.

THE MULTIPLE APPLICATIONS OF INFRASTRUCTURE 4.0

The Industry 4.0 technologies may impact every stage of the **infrastructure lifecycle** (planning, design, construction, operation, service) by introducing new digital processes (Figure 5). Facing these multiple technological breakthroughs, infrastructure must focus on long-term value creation.

◇ Data collection
The IoT describes a **wide ecosystem where interconnected devices** (sensors, software, network connectivity, computing power) **and services collect, exchange and process data** in order to adapt dynamically to a context. The global development of IoT devices has enabled information to be collected from places or situations that were previously out of reach, generating an exponential increase in data to be analyzed.

Coupled with **data analytics,** it contributes notably to:
⟶ **Planning:** Data generated by IoT opens valuable opportunities for providers to gain more accurate and timely information about the infrastructure environment. For example, sensors installed in transportation infrastructures can provide urban planners with data describing the needs of travelers and can feed analytical models for better decision-making;

APPLICATIONS OF THE INDUSTRY 4.0 IMPACT EVERY STAGE OF THE INFRASTRUCTURE LIFECYCLE

[6] PWC, "Capital efficiency meets Industry 4.0: the capital projects and infrastructure business case"; Deloitte (2015), "Industry 4.0: Challenges and solutions for the digital transformation and use exponential technologies"
[7] Atkinson, R., Castro, D., Ezell, S., Mcquinn, A., New, J. (2016), A policymaker's guide to digital infrastructure, information technology & innovation foundation

FIGURE 4
THE FOUR INDUSTRIAL REVOLUTIONS
Source: Altermind

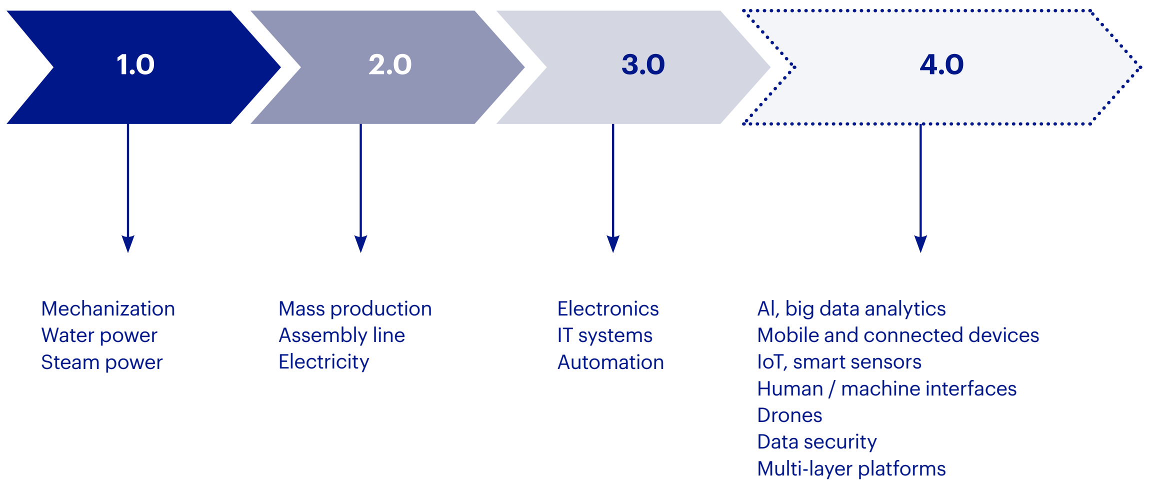
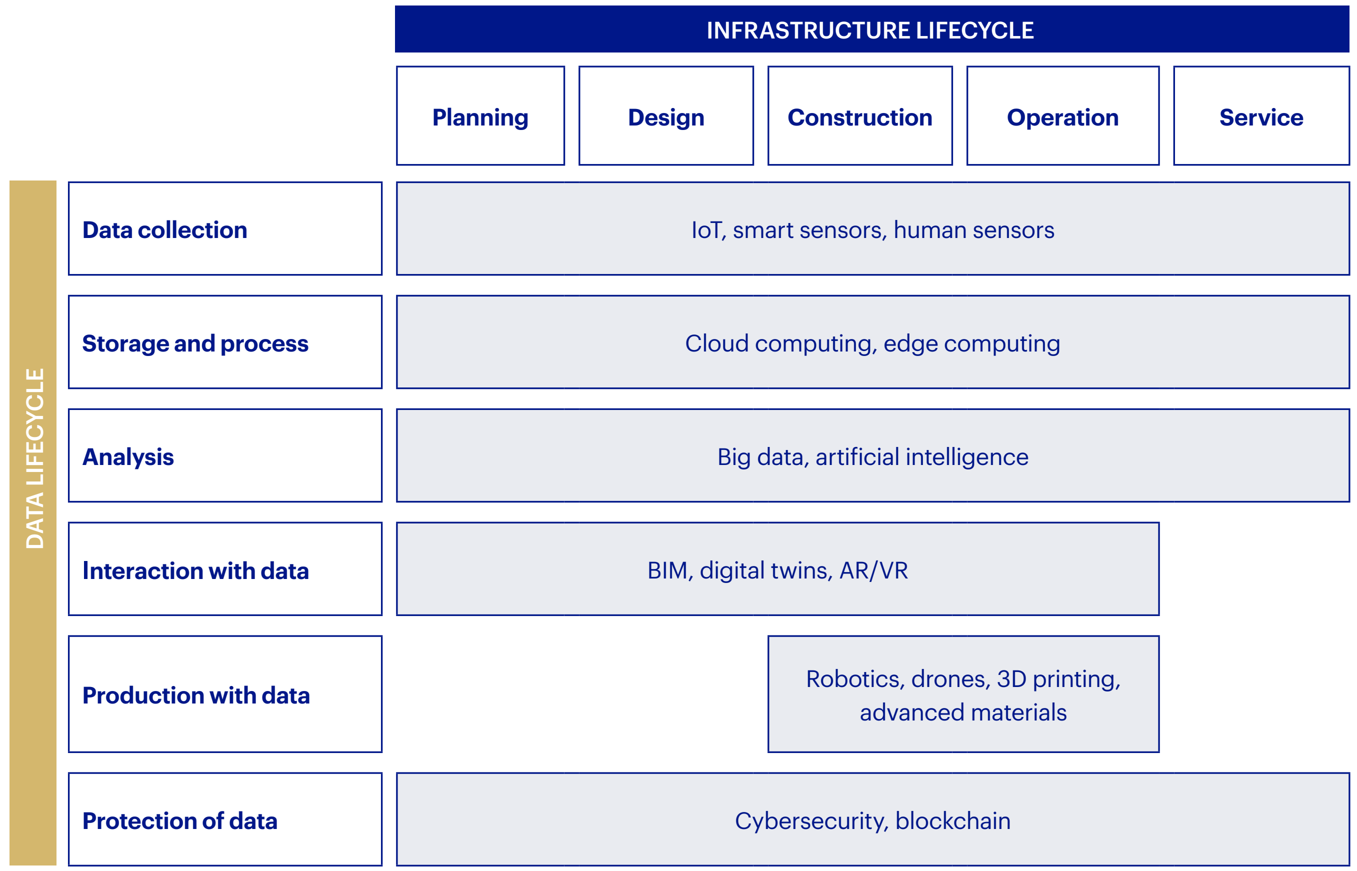


FIGURE 5
APPLICATION OF THE INDUSTRY 4.0 TECHNOLOGIES TO INFRASTRUCTURE
Source: Altermind



EXPERT POSITION 2 / Diego Marin Garcia is the managing director of Acciona Concesiones.
Acciona is a Spanish company dedicated to the development and management of sustainable infrastructure (construction, water, industrial and services) and renewable energy.

As part of its digital transformation, Acciona is focusing on transforming infrastructure into smart assets, optimizing costs and providing safer services to users as well as workers.

"All the different businesses of Acciona work together to transform ideas into new efficient technological developments, helping to build sustainable infrastructures because we believe in sustainability as a tool to obtain **more efficient, safer and more profitable projects**. In recent years, we have focused our efforts on adapting new and mature infrastructures into safe and intelligent assets. We are applying new emerging technologies like the IoT, data analytics, robotics, etc., to carry out projects that are changing the way in which we are maintaining our infrastructures with very satisfying results.

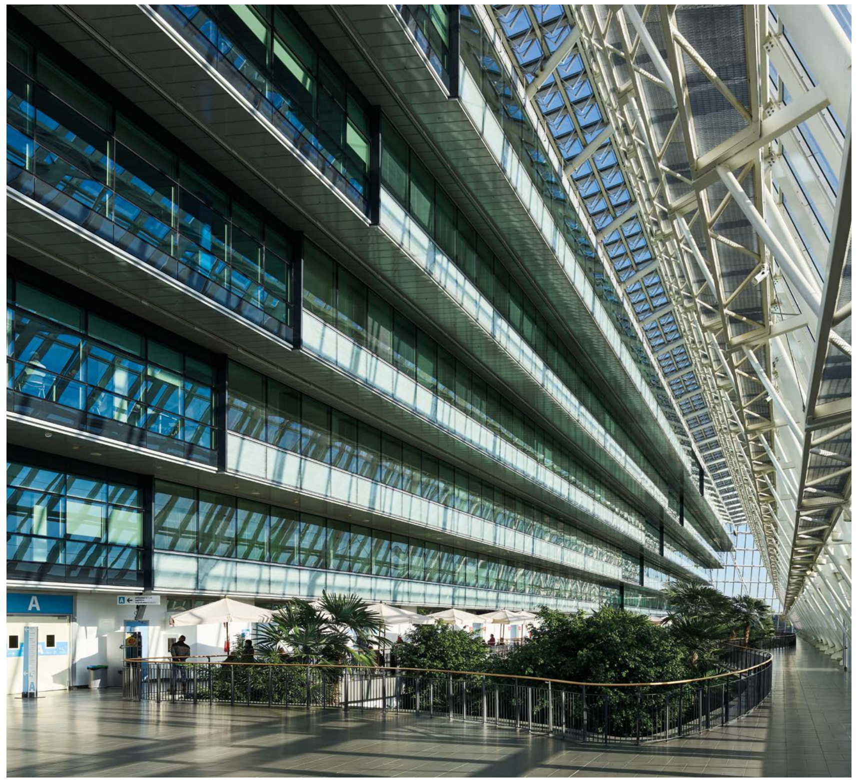
In respect of highways, we have developed initiatives focused on two main areas: **predictive maintenance and risk prevention.** We are currently monitoring elements to carry out predictive data models, which allow us to **anticipate the preventive maintenance tasks in order to reduce the corrective ones.** For example, we have installed corrosion sensors in concrete structures, we are using drones to monitor erosion on slopes, or we are working on the optimization of winter road activities through the installation of several micro weather stations along the road. The information captured from the road not only allows us to have **online information of the status of the road,** but it will also feed predictive models to optimize our maintenance works in order to increase the useful life of these elements and make them safer.

Another very important concern for us is to **increase the occupational risk prevention** for our team. In this sense, Acciona has implemented technology to monitor the health of the team and the environment in which they are working all the time, so they can be warned when they are in a risky situation and give them the help they need to stay safe. Also in this topic, we have carried out a system to prevent road accidents for maintenance operators during lane closures. It detects vehicles with a real risk of entering into the operators' safety area, so the staff is immediately notified and they can protect themselves. To achieve this goal, a radar and a thermal or HD camera are used to create alarms automatically on their smartphones and their electronic wristbands.
In building projects, such as hospitals, we are working on the integration of different digital tools, such as BIM models, SCADAs, CMMS, etc., to optimize the maintenance of the facilities. Given the global health situation, Acciona is also working on risk mitigation measures in hospitals, such as cleaning facilities through autonomous robots, or the control of the occupancy and safe distance between users through image processing. This last information allows the infrastructure managers to receive alarms and to be able to control those situations that could be a risk to the health of the medical professionals and users."

acciona

CASE STUDY 2–HOSPITAL 4.0

"Hospital 4.0" is an organization that transforms data into usable information and relies on analytics, IoT, 3D printing and virtual simulation to optimize operations and provide better healthcare services. Advances in machine learning and sensors have developed "ambient intelligence," which consists of physical elements having computing, communication and data processing capabilities, optimizing the use of physical space by being more responsive to the presence of humans. Contactless sensors embedded in the environment are able to optimize how space is used within hospitals and improve healthcare services (Figure 6): "in daily living spaces, ambient intelligence could prolong the independence of older individuals and improve the management of individuals with a chronic disease by understanding everyday behavior. [...] Thoughtful use of this technology would enable us to understand the complex interplay between the physical environment and health-critical human behaviors[8]."



[8] Haque, A., Milstein, A., Fei-Fei, L. (2020), Illuminating the dark spaces of healthcare with ambient intelligence, Nature 585, 193-202

FIGURE 6
CONTACTLESS SENSORS FOR AMBIENT INTELLIGENCE
Source: Haque, A. and al.

	CAMERA	DEPTH SENSOR	THERMAL SENSOR	RADIO SENSOR	ACOUSTIC SENSOR
Sensory information	RGB, color, video	Lidar	Infrared	Radar, Wi-fi	Microphone
Function	Measures color (visible light)	Measures distance to objects	Measures surface temperature	Estimates distance and velocity	Measures air pressure waves
Bit depth	24 bits	16 bits	16 bits	32 bits	16 bits
Uses	Object recognition	3D object detection, robotic	Night vision, equipment safety	Motion detection, object detection	Speech recognition

These new technologies must be considered as a global system to explore interoperability opportunities between assets. This involves collaborating with other platforms and health players (transportation companies, pharmacies) to ensure patient engagement in the whole care pathway.

Operation: The IoT helps infrastructure managers to better control, manage, and monitor infrastructures, thereby improving efficiency and increasing sustainability. For example, by providing data on rail temperature and detecting the slightest defect, the IoT (or IoV: Internet of Vehicles) system monitors the entire rail network and allows preventive identification of the slightest problem. Maintenance is prioritized, so digital monitoring makes all systems secure and reliable[7];

Pricing: Smart infrastructures simplify the collection and analysis of data for a better pricing of services, ensuring that supply and demand are more closely aligned. For example, smart-metering technology enables to have better knowledge of energy consumption and the ability to adjust pricing in order to match supply and demand, in particular during peak hours.

◇ Storage and process

With **cloud computing,** a network of remote servers hosted on the Internet can store, manage, and process data, instead of hosting them on a personal computer or an on-premise server. Cloud computing has provided the capacity to **face data explosion and gain significant speed and agility** in many industries, including infrastructure.

◇ Data analysis

To analyze data, AI uses algorithms capable of performing tasks that are generally associated with human intelligence: visual perception, image analysis, forecasting, understanding language, solving problems, and learning.

AI is particularly used in the utility sector, where applications are very diverse: **predictive maintenance, modeling for risks and performance, real-time insights** (regarding availability or water quality for instance), **better management of supply and demand** (e.g. smart grids in the energy sector).

The White Paper of the European Commission on AI has recently underlined AI[9] development potential within healthcare and transport services, where technology is mature for large-scale deployment. AI is also key in the development of autonomous vehicles, to harvest and interpret data from sensors (cameras, radars, lidars).

With machine learning, AI provides systems with the ability to automatically learn and improve from experience without being explicitly programmed. Machine learning shows a strong disruptive potential within the infrastructure sector, especially when applied to the fight against climate change through either effective engineering or innovative research (Figure 7).

◇ Interaction with data

Digital models of buildings (BIM) are objects or processes (digital twins) that revolutionize the design, construction and operation of buildings and infrastructure. Fed with data harvested by IoT devices, those technologies use AI to improve decision-making, management (e.g. motorways) and performance throughout projects lifecycles.

◇ Production with data

With **robotics,** human activities are assisted, automated and augmented, through self-learning capabilities. In the case of infrastructure, robots help with the inspection of bridges, maintenance in transport, underground pipe condition assessment, and container-handling vehicles.

◇ Protection of data

With **blockchain,** a digital database is shared within a large, decentralized, publicly accessible and uncorruptible network and is used to record and confirm transactions with reliability and anonymity. Transparency is improved for asset management (e.g. certification of renewable energy) and software attacks are prevented. As for all sensitive technologies, where traceability (in particular of maintenance) is key, blockchain is a promising development avenue.

(9) European Commission (2020), White paper on Artificial Intelligence–A European approach to excellence and trust

FIGURE 7
CLIMATE CHANGE SOLUTION DOMAINS, MATCHED WITH SELECTED AREAS OF MACHINE LEARNING (ML)

Source: Haque, A. and al.

	Causal inference	Computer vision	Interoperable models	Time-series analysis	RL & Control	Transfer learning	Uncertainty quantification	Unsupervised learning
ELECTRICITY SYSTEMS								
Enabling low-carbon electricity		•	•	•	•		•	•
Reducing system impact		•		•			•	•
Ensuring global impact		•				•		•
TRANSPORTATION								
Reducing transport activity		•		•			•	•
Improving vehicle efficiency		•			•			
Alternative fuels & electrification					•			•
Modal shift	•	•		•			•	
BUILDING AND CITIES								
Optimizing buildings	•			•	•	•		
Urban planning		•		•		•		•
The future of cities						•	•	•
SOCIETAL IMPACTS								
Ecology		•				•		
Infrastructure				•	•		•	
Social systems		•		•				•
Crisis		•						
CLIMATE PREDICTION								
Unite data, ML, climate science		•	•	•			•	
Forecasting extreme events		•	•	•			•	

CASE STUDY 3
INDUSTRY 4.0 TECHNOLOGIES IN THE RAILWAY SECTOR[10]

The railway sector is currently facing many challenges in terms of technology upgrade, low-carbon transition and multimodal competition. Using the concepts and technologies developed through Industry 4.0, the sector is in the process of reinventing itself. Therefore, digitalization is an opportunity for the railway industry to create value: optimizing the performance of infrastructures, reducing maintenance costs, creating new mobility solutions, and seizing new growth opportunities.

Some technologies of the 4th industrial revolution can be useful in the short term to face obsolescence, such as:

→ **Drones:** Widely used by infrastructure managers, industrial drones are an efficient way to monitor installations and equipment (bridges, high voltage installations, IT antennas) while keeping them under operation. Drones allow 4D monitoring of rail infrastructure, which covers a range of needs from functionality assessments to exhaustive data storage for comparative analysis and predictions to optimize maintenance. For instance, SNCF experimented flying drones with an infrared camera to monitor the temperature of electrical installations. Drones are also used to study topography, map the network, and ensure safety (spot human presence);

→ **Robotics:** Many different types of robots/cobots/exoskeletons are able to improve employee's working conditions. However, heavy integration work necessarily needs to match with industry needs, which make it cost effective only in specific conditions;

→ **IoT:** As sensor costs are getting lower and lower, railways are deploying thousands of sensors. Many types of sensors are able to improve the infrastructure operations and safety: obstacle detecting sensors, rail crossing sensors, rail friction sensors, ice sensors, etc. As a result, the quality and consistency of data is improving and infrastructure can be monitored and inspected remotely if abnormalities are spotted. However, in some cases, theoretical models are accurate enough and more cost effective.

Other technologies lead to deeper change for the railway industry:

→ **Aerial view** can replace the surveillance tour;

→ **Virtual Reality and Augmented Reality** (VR/ AR), already in use for the design phase is now useful for learning or maintenance;

→ **Additive Manufacturing** (AM) can create spare parts that are discontinued, in order to drastically reduce stocks of old parts, improve the reliability of the network, lower order quantities and lower costs for producing parts with complex geometries. Up to one third of spare parts could be built with AM. To make the technology available to the market, European operators and the AM-industry are collaborating through the "Mobility goes Additive" network.

In some cases, the incorporation of Industry 4.0 technologies can be a source of "internal" disruption:

→ **Inspection infrastructure** can be disrupted by new technologies, especially camera drones for visual inspection;

→ **Catenary** overhead lines and electricity storage systems (batteries or hydrogen) are competing;

→ **Different architectures can deliver the same service**. For example, for tracking freight wagons, the North American Railway uses wayside systems, while in Europe operators deploy connected boxes with GPS and various sensors on board.

[10] Source: Guillaume Gazaignes, Workshop 2

DIGITALIZATION: A CRITICAL CHALLENGE FOR INFRASTRUCTURE

◇ An "Infrastructure 4.0 gap"?

Compared to other sectors, **infrastructure is said to lag behind in respect of digitalization.** In its report on bringing Industry 4.0 to infrastructure, the World Economic Forum emphasizes the fact that this sector is still struggling to embrace the promise of the new technological era:

"Although infrastructure is critical for society, the integration of new technologies into infrastructure planning, development and delivery lags behind other sectors. ***The brave new world of innovation, changing the way the rest of society works, seems to be passing by the sector.*** *(...) Infrastructure is at a crossroads: should it continue down the well-trodden path or move toward an exciting new horizon?[11]"*

Although some sectors (such as Telecommunications or energy) seem more advanced than others (such as transportation), infrastructure does not perform well, as illustrated with AI adoption (Figure 8).

This may be explained by various factors[13]:

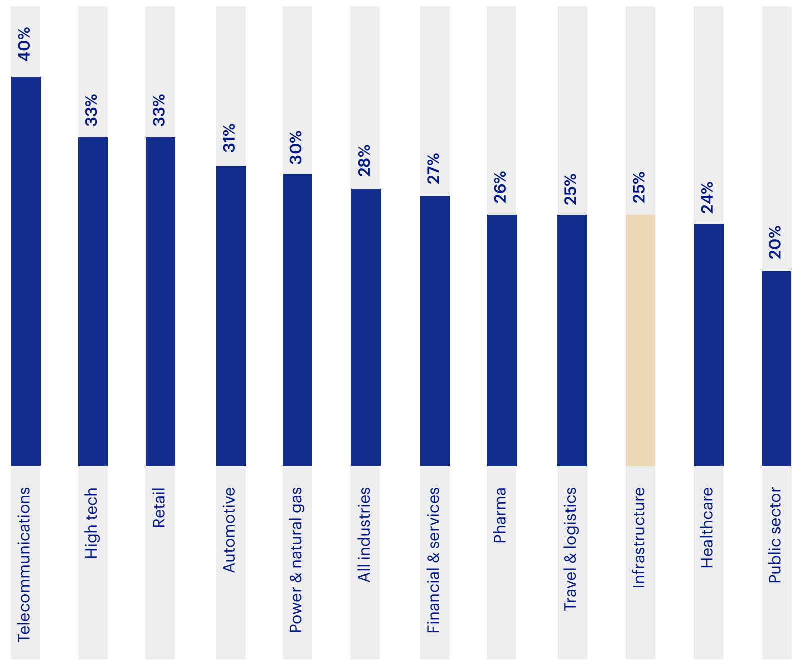
⟶ **The bulk of infrastructure** in developed countries was built before the start of the 21st century, during the so-called **"analog" era,** and was built to last for at least several decades requiring little change. As the World Economic Forum states, infrastructure is generally seen as a "stable provider," meaning there is little incentive to upgrade it as long as it keeps providing the same basic services;

⟶ At the rate of modern technology's evolution, potential technological obsolescence is a relevant issue. Because **there is a chance that technology built into an infrastructure will not be relevant several decades from now, there is little incentive to innovate;**

FIGURE 8

AI ADOPTION WORLDWIDE 2019, BY INDUSTRY (SHARE OF RESPONDENTS[12])

Source: McKinsey, Statista



(11) World Economic Forum (2019), Transforming Infrastructure: Frameworks for Bringing the 4th Industrial Revolution to Infrastructure

(12) Percentages shown are the arithmetic average of service operations, product development, marketing and sales, manufacturing and supply chain management

(13) World Economic Forum (2019), Transforming Infrastructure: Frameworks for Bringing the 4th Industrial Revolution to Infrastructure

(14) World Economic Forum (2019), We're helping to close the global infrastructure investment gap by mobilizing the private sector

(15) World Economic Forum (2019), Transforming Infrastructure: Frameworks for Bringing the 4th Industrial Revolution to Infrastructure

(16) World Economic Forum (2019), We're helping to close the global infrastructure investment gap by mobilizing the private sector

⟶ **Public procurement** is not very open to innovation, because of the rules governing tenders and public financial constraints;

⟶ There is already an **extensive infrastructure investment gap:** Stakeholders are usually reluctant to invest in maintaining current structures. It is thus not surprising that infrastructure does not benefit from technological updates. Before the Covid-19 crisis, the gap between projected infrastructure spending and the amount to meet the world's infrastructure needs was already estimated at $15 trillion by 2040[14].

◇ Key enablers for Infrastructure 4.0

Considering the significant gaps in the adoption of technology and the use of data in infrastructure decision-making, **the digitalization of the infrastructure sector depends on various levers,** among which:

⟶ **Appropriate incentives to innovate:** The regulatory framework has to promote disruptive strategies and innovation;

⟶ **A greater openness to innovation:** Infrastructure systems must be designed with an eye toward potential future developments. Finding ingress points for new technologies during the initial stages of planning and maintaining the flexibility to adapt to unforeseen technological changes, is crucial[15];

⟶ **Internal organizational changes:** Infrastructure is struggling to extract value from data. Connecting data requires a range of new skills, with many organizations facing technological obstacles in integrating data sets. Engineering expertise is crucial, but technology skills and data science skills are also important. Maintaining data integrity and personal privacy is a priority as well. As stated by Ari Koponen (Loiste), "recruitment has become a key challenge for the past years in the infrastructure sector. Digitalization is a strong competitive advantage to attract young high-skilled professionals";

⟶ **Cross-industry collaboration** between different actors drives Infrastructure 4.0, for carrying-out R&D and innovation programs but also for implementing projects requiring a holistic view;

⟶ **Bridging the infrastructure gap,** relying on private finance. As stated by the World Economic Forum, *"a holistic approach to infrastructure considers the private sector potential for introducing efficiency into service deliveryand explores diverse forms of financing–promoting the judicious use of scarce public and concessional resources to bring in commercial capital and minimize public debt while delivering sustainable and affordable services[16];"*

⟶ **New business models,** such as platform-based business models are very relevant and competitive for Infrastructure 4.0. Platform-based ecosystems can create digital communities and marketplaces that allow different players to interact. In these models, crowdsourcing and networks effects are of major importance.

⟶

INFRASTRUCTURE HAS TO ACTIVATE VARIOUS LEVERS TO ACCELERATE ITS DIGITAL TRANSFORMATION

KEY TAKEAWAYS

A resilient infrastructure refers to the ability of an asset to absorb, recover from or transform itself when confronted with various events (such as climate change, pandemics, conflicts, etc.).

With the Covid-19 crisis, the need to provide a resilient infrastructure has become even more important. Digitalization can be an efficient way to enhance resilience of interdependent infrastructures.

Smart city technologies can improve resilient urban ecosystems through microservices, big data, social media and platforms for collaboration.

INFRASTRUCTURE 4.0: A RESILIENCE ENABLER IN THE POST-COVID-19 WORLD...

WHAT IS A RESILIENT INFRASTRUCTURE?

Infrastructure has been critical for the response to the Covid-19 crisis and will also be crucial for the future recovery. To face future crises, resilient infrastructures will be necessary and make the difference between robust and struggling societies.

Resilience refers to the ability to absorb, recover from or transform when confronted with various events, i.e. a natural disaster, a catastrophe caused by climate change, war or terrorist action, a social conflict or an economic shock. It is a dynamic property that has been linked to complex adaptive systems, such as urban systems.
The US National Infrastructure Advisory Council (NIAC) has established a **framework for resilient infrastructure** (Figure 9). Originally created by Stephen Flynn, this model emphasizes that resilience is a **dynamic and emerging property of systems and requires continuous dynamic action,** rather than a one-off response.

It relies on the following features[17]:

- **Robustness** is the quality of infrastructures able to endure the impacts of hazards without significant damage. In physical infrastructures (including bridges and airports), this means designing structures so as to preserve functionalities during unexpected events;
- **Resourcefulness,** which involves the management of the event while it occurs, from organizing people and personnel, using infrastructure in the best way possible, to controlling any kind of damage;
- **Recovery,** which refers to the speed with which disruption is overcome and safety is restored. This requires advanced planning, including emergency operations and contingency plans. But it also means dealing with economic shocks to restore the economy, repairing any infrastructure that was unable to withstand the shocks, and supporting communities;
- **Adaptability,** which depends on the

INFRASTRUCTURE RESILIENCE IS THE CAPACITY OF AN INFRASTRUCTURE AND ITS RELATED SYSTEMS TO ADAPT AND RESPOND POSITIVELY TO UNEXPECTED EVENTS

[17] National Infrastructure Commission (2017), Digitally Connected Infrastructure System Resilience Literature Review (UCL)
[18] National Infrastructure Advisory Council (2010), A Framework for Establishing Critical Infrastructure Resilience Goals Final Report and Recommendations by the Council

FIGURE 9
THE SEQUENCE OF THE NIAC RESILIENCE CONSTRUCT
Source: NIAC[18]

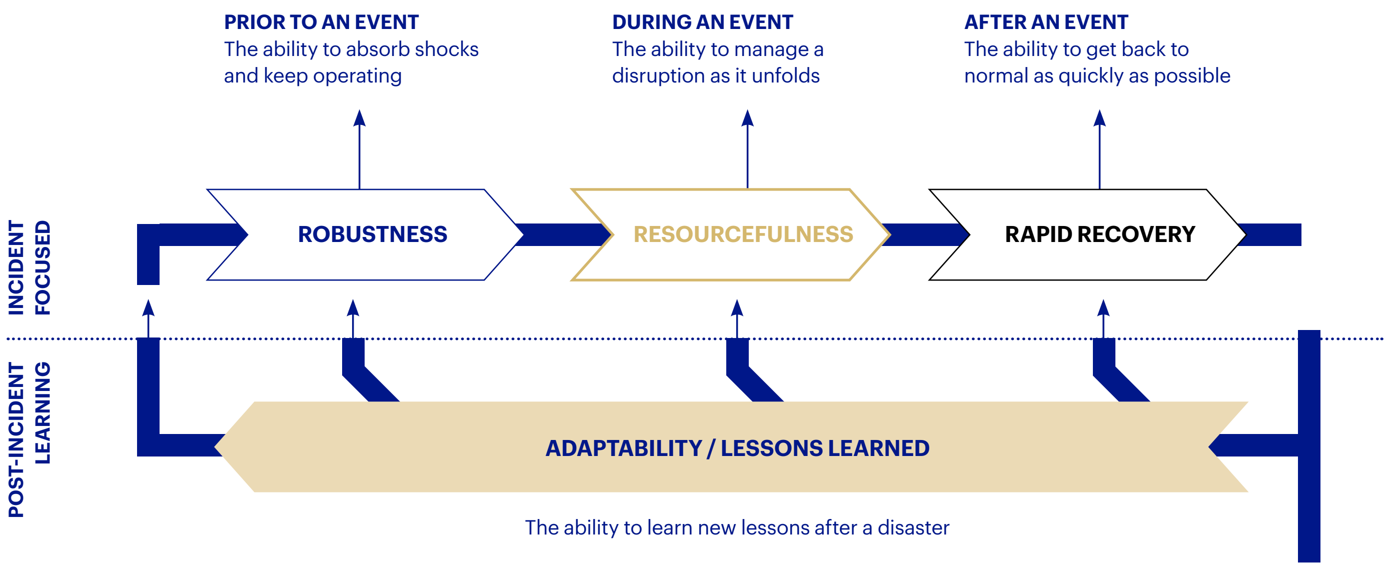
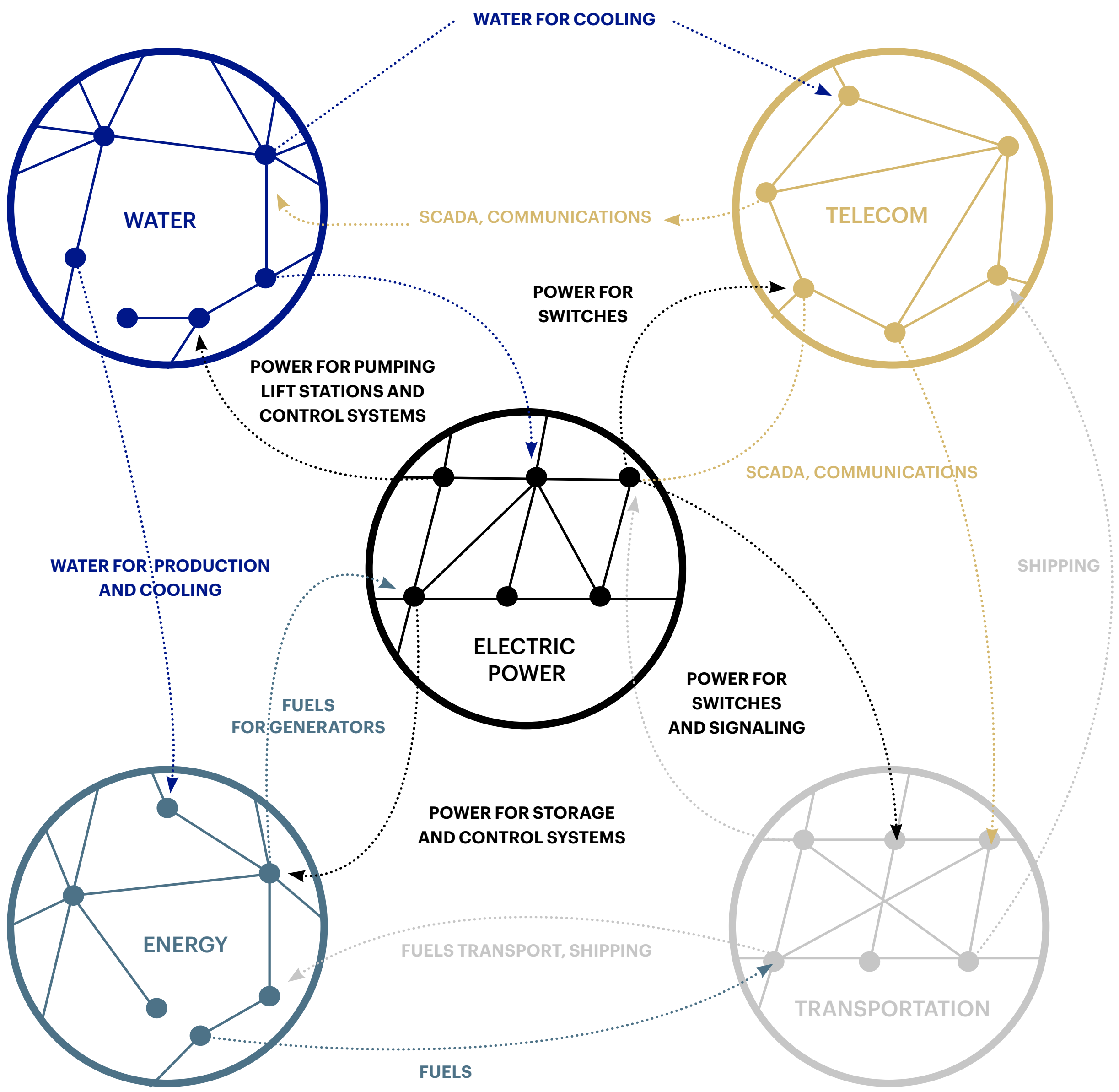


FIGURE 10
INTERDEPENDENCIES OF URBAN INFRASTRUCTURE
Source: Jianxi Gao and al. (2015)



ability to integrate the return on experience after a disruption. This includes avoiding future construction in high-risk areas and identifying issues in communication during disaster management.

Current physical infrastructures are under pressure from expansive growth, rapid increase in population, extreme and unpredictable weathers, cyber-attacks, geopolitical tensions, climate change, etc. **Between 2000 and 2012, natural disasters alone** (weather, health, seismic events) **caused more than $1.7 trillion in damages related to impacts on infrastructure,** communities and the environment, with decreases in business profitability and economic growth[19]. This explains why the United Nations (UN) has set resilient infrastructure as one of the Sustainable Development Goals (SDG)[20].

The Covid-19 crisis –and health crisis in general– poses an additional risk for the infrastructure sector. According to the UN, **"the coronavirus pandemic has revealed the urgent need for resilient infrastructure"[21].**

DIGITALIZATION: A RESPONSE TO THE CHALLENGES OF RESILIENT INFRASTRUCTURE AND CITIES

In the current crisis context, **digitalization can be a resilience enabler.** In the private sector, digitalization has already significantly reduced exposure to risk and improved resilience[22]: infrastructure should follow the same path.

◇ Digitalization as an answer to dependencies and interdependencies[23].
Infrastructure resilience is difficult to accomplish in part because of the **various dependencies / interdependencies between assets.** Infrastructures rarely function in isolation and usually have a relationship with others.

In this context, dependencies and interdependencies are key points to consider in a **global infrastructure ecosystem:** for instance, a hazardous event can result in a loss of a service (e.g. electric outage), which will impact the critical infrastructure using this service and the critical infrastructure dependent upon that same service[24].

As a result, when building resilient infrastructure, especially in an urban environment, it is vital to take into consideration dependencies and interdependencies because it can be risky for an important function to only be dependent on a single component (Figure 10)[25]. These relationships are made of **multiple connections between infrastructures, feed-forward and feed-back paths.** They create an intricate system, which can broadcast shocks from one infrastructure to the others.

Facing this challenge, digitalization can be an efficient way to enhance resilience of interdependent infrastructures, especially within urban areas, as outlined by the 100 Resilient Cities[26]. **Digitally connected infrastructure systems (DCIS)[27]** will increase complex interactivity, and simultaneously enable an infrastructure system to perform in ways closely aligned to outcomes now expected.

→

A STRONG RESILIENCE PLAN CAN REDUCE THE RISK AND IMPACT OF HAZARDOUS EVENTS AND SPEED RECOVERY, IN PARTICULAR IN THE URBAN ENVIRONMENT

(19) IBM,"21st Century Emergency Management"
(20) SDG 9 refers to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation"
(21) Sarkar-Swaisgood, M. (2020), "COVID-19 reveals urgent need for infrastructure," UN ESCAP
(22) OECD (2020), Building back better: a sustainable, resilient recovery after Covid-19
(23) Source: Nicos Komninos, Workshop 3
(24) Argonne National Laboratory (2015), Analysis of critical infrastructure dependencies and interdependencies
(25) National Infrastructure Commission (2017), Digitally Connected Infrastructure System Resilience Literature Review (UCL)
(26) Berkowitz, M., Matus Kramer, A. (2018), "Helping cities drive transformation: the 100 resilient cities initiative," Resilient cities
(27) National Infrastructure Commission (2017), Digitally Connected Infrastructure System Resilience Literature Review (UCL)
(28) Source: Cristina Kakderi, Workshop 3

◇ Smart cities as resilient cities[28]

A smart city is a territory that brings innovation systems and information and communication technologies (ICT) within the same territory, combining the creativity of talented individuals that make up the population of the city, institutions that enhance learning as well as innovation, and knowledge management[29]. This is a city in which **ICT is merged with traditional infrastructures, coordinated and integrated using new digital technologies.**

In this context, the density of infrastructure within smart cities makes them interesting cases to consider when building a resilient interdependent ecosystem. Furthermore, smart cities are also **tools to improve competitiveness in order to strengthen communities and quality of life[30].**
Smart cities seek to be resilient. Resilient cities develop systems to monitor various interdependent systems, cultivate processes for adapting to changes, and govern these systems in inclusive ways. They promote sustainable development, well-being and inclusive growth.

Smart cities and resilient cities share some common attributes. Indeed, there is a broad overlap between characteristics attributed to each of these concepts: **adaptability** to unforeseen situations; **collaboration** between stakeholders; **creativity** facing new situations; creation of networks allowing sharing of ideas, resources and services; **innovation** (new ways of organizing society, rules and institutions), constant **monitoring, optimizing** performance, involving civil society, being aware of strengths and weaknesses. As a result, resilience can be considered as a feature of smart **systems.**

Smart cities provide technologies able to facilitate resilience in urban infrastructure. From this perspective, three main technologies are critical:

- ⟶ **Microservices:** An architectural approach to smart city services based on microservices, supports decentralized and modular components enhancing resilience, adaptability, scalability and flexibility of smart city services. Resilience is provided by singling out all the services that provide components with clear boundaries. This enables to isolate failures and gradually degrade the system functionality, as well as to update and deploy individual services independently;
- ⟶ **Big data, analytics, AI, predictive modeling and forecasting:** These technologies contribute to reducing vulnerability and the potential of systemic risks due to system interdependencies (e.g. monitoring, scenario analysis, alert);
- ⟶ **Social media and platforms for collaboration:** Social media, which promote participation, networking capacity and collaborative innovation, can improve response through behavior adaptation, resource mobilization and user-driven innovation. For instance, social media can crowdsource geographic information for disaster management during earthquakes, hurricanes, flooding, or other natural or man-made disasters. This allows rapid knowledge dissemination, as well as regular and proactive communication and engagement with the public and at-risk populations, and supports the establishment of situational awareness.

⟶

SMART CITY TECHNOLOGIES ENHANCE RESILIENT URBAN ECOSYSTEMS

(29) Komninos, N. (2013), Intelligent Cities: Innovation, Knowledge Systems and Digital Spaces
(30) Johansson, A., Batty, M. (2012), "Crowd and environmental management during mass gatherings," The Lancet Infectious Disease, Volume 12, Issue 2, 150-156

EXPERT POSITION 3 / **Ari Koponen is a director of the board of Loiste.** Loiste is one of Finland's largest electricity suppliers, providing Finns with products and services that promote energy efficiency and energy savings. Within the group, Kajave Oy is the company responsible for the construction, transmission, operation and maintenance of the electricity network.

"There are often disturbances in the electricity supply, not all of which can be prevented. Smart grids mix multiple technologies that enhance the automation, operability and control of the infrastructure.

These technologies increase resilience during a crisis, such as a power outage. In practical terms, with remote connectors and AI, one can easily isolate the fault, minimize damage and recover rapidly.

Digital solutions are enablers for better safety procedures, more efficient damage control and more flexibility facing customer expectations."

loiste

CASE STUDY 4– THE ONDIJON SMART CITY PROJECT[31]

Dijon Métropole launched in 2019 an unprecedented project in France to develop an intelligent metropolis. Within this smart city, the management of public space and the modernization of public action are at the heart of new services for citizens. The OnDijon project relies on remote management, from a Connected Control Station (CCS) for all urban equipment (traffic lights, street lighting, video protection, etc.) of the 23 municipalities composing Dijon Métropole.

Investment in infrastructures were significant: more than 140 kms of optical fibers were deployed across Dijon to connect public infrastructures to the CCS; 205 geolocated vehicles and 130 vehicles equipped with radio were added to city departments' forces; 180 critical public buildings, among which 13 were renovated, were connected to the CCS.

Thanks to data, the **OnDijon CCS facilitates and better coordinates service interventions.** It brings together various separate command posts that were previously separated: security, police, urban lighting, urban traffic supervision, transport, etc. **With open data, information is reliable and retrieved in real time from operators, equipment and services.** This unique system in France thus strengthens the city's decision-making processes, particularly in the wake of a crisis, by providing relevant operational solutions.

Facing the Covid-19 health crisis, Dijon relied on its smart city infrastructure making the coordination of services more efficient. Equipment was increasingly controlled remotely, with fewer agents in the field. The metropolis also transformed its **Allo Mairie** service to accompany its citizens during the lockdown period: It is now a toll-free number accessible 24 hours a day for asking any questions related to the crisis, except for medical questions. Regarding current projects and challenges, water services will join the steering center in April 2021 in order to manage flood hazards, and city buildings are currently being mapped in 3D.

According to Pierre Vanstoflegatte, CEO of the Bouygues Construction Energies & Services Division, *"the OnDijon project shows two key factors of success of smart cities:* ***the importance of the political involvement of the mayors and the necessity to transform the relationship between citizens and public services.*** *The pure technical aspect is secondary in comparison to these key factors."*

[31] OnDijon, "Métropole intelligente et connectée"

KEY TAKEAWAYS

Data can create incremental value for infrastructures by improving operations / making them more cost efficient but also by providing the bedrock for new business models (data analytics, data pooling).

The current EU environment is all the more favorable for these business developments as the new Commission is reviewing a new set of rules that will give birth to a European market for industrial data. Given its data potential, the infrastructure sector shall become a key contributor to this new market.

...AS WELL AS AN AVENUE FOR FURTHER UPSIDE[32]

THE STRONG DATA POTENTIAL OF INFRASTRUCTURE

Considering the diversity of data generated by infrastructure assets, digital infrastructure has a strong potential, especially in the context of the data strategy being designed by the European Commission.

◇ The infrastructure data flow

From a general perspective, companies produce a lot of data through and for their own usage. This is **industrial data,** which can be defined as data related to logistics, to their activity with their customers or suppliers, to stocks in the points of sale, information on the customers' journey, etc.

This is particularly true in the case of the infrastructure sector. Infrastructure data is characterized by its diversity:

→ Every infrastructure asset generates **three main types of data: structural data,** describing the characteristics of the infrastructure asset itself; **activity data,** meaning reporting data on the use of the infrastructure asset; and **real-time data,** which is the most valuable data;

→ Data generated by the infrastructure sector can be **personal** (information related to an identifiable person, which can be physical, physiological, economic, cultural, political, social, etc.) **or industrial data** (information generated by industrial equipment, such as sensors' data, assets metadata, etc.);

→ **Various stakeholders** may produce this data, and in particular **the asset manager, the end-user or the public entity.** They may retain it to derive value from it or be under the obligation to share it (Figure 11).

In 2001, Doug Laney highlighted the three dimensions of data management, later known as "**the three Vs of big data":** volume, velocity and variety[33].

This vision remains relevant: a key challenge for infrastructure asset managers is therefore to **generate data with high volume, velocity and variety.**

◇ Infrastructure and the European data strategy[34]

The European data strategy set out in 2020 by the European Commission raised a key observation: data is the **new asset for industrial and personal purposes** as well as an essential **instrument of governance** in our societies:

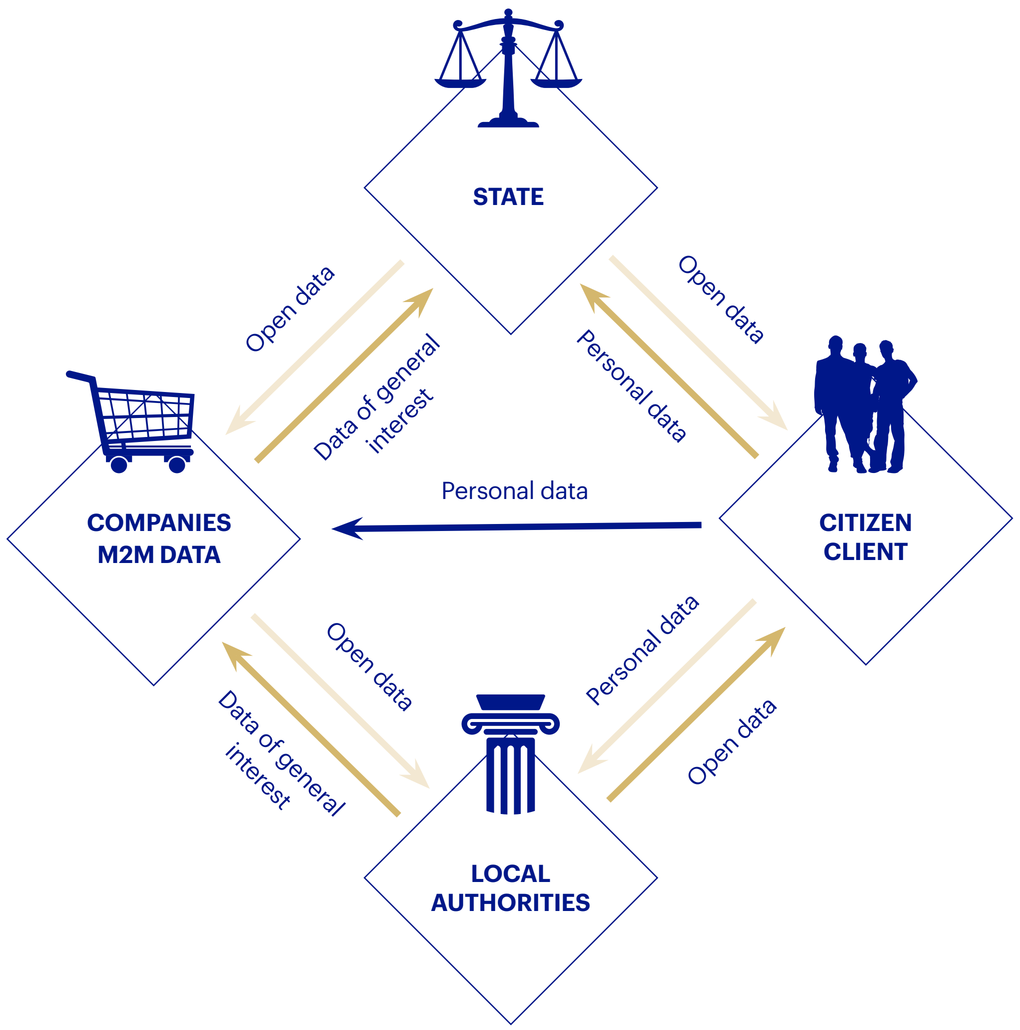
"Making more data available and improving the way in which data is used is essential for tackling societal, climate and environment-related challenges, contribut-

→

INFRASTRUCTURES GENERATE HIGH VOLUME DATA, WHICH MUST BE MANAGED EFFICIENTLY

FIGURE 11
THE INFRASTRUCTURE DATA FLOW

Source: Henri Isaac for Altermind



[32] Source: Henri Isaac, Workshop 4
[33] Laney, D. (2001), "3-D Data Management: Controlling Data Volume, Velocity and Variety," Meta Group
[34] Source: Adrien Basdevant, Workshop 4

*ing to healthier, more prosperous and more sustainable societies (...). **The EU can become a leading role model for a society empowered by data to make better decisions**–in business and the public sector*[35]*."*

However, **data is held by a small number of players.** The European data strategy hence aims at promoting data sharing frameworks that encourage equitable data value sharing and promote data alliances. The infrastructure sector could be one of the major beneficiaries of this strategy. From this perspective, four main data sharing frameworks should be distinguished:

- **Business-to-business data sharing (B2B):** Companies may wish to share their data with others in order to create value, whereas other parties express the need to control the rights to access and use of their data. This can be done through data sharing agreements, which should focus on (i) securing transparency between parties; (ii) recognizing shared value creation; (iii) respecting the interests of each party; and (iv) ensuring undistorted competition when exchanging sensitive data;
- **Business-to-government data sharing (B2G):** The European data strategy will provide a new framework for the re-use by the public sector of data held by private actors for public utility reasons. In France, regulations on "data of general interest" (a concept which has yet to be properly defined) already exist, and are notably applicable to data emerging from public service concessions, and thus to many infrastructure assets and related services (water, waste, transport, etc.);
- **Government-to-business data sharing (G2B):** The directive 2019/1024, known as "PSI III," aims to open up major public data sets to private actors in order to boost innovation. The European Commission will define "high-value data series" –which may encompass geospatial, environmental, meteorological, statistical or business data sets–and specify the modalities for re-use of these sets. France has decided to adopt a sectoral strategy in the matter, including the energy sector and the transport sector. For example, the transport.data.gouv platform operated by Etalab gathers data related to mobility in France and offers the possibility to connect dynamically to application programming interfaces (APIs), in order to obtain direct access to data flows;
- **Government-to-government data sharing (G2G):** Data sharing may create some challenges to infrastructure managers. For instance, forcing companies to share their data with the public sector and complying with open data requirements may endanger some business models. However, all in all, data should be considered as an opportunity, fostering value creation through data-driven business models

[35] European Commission (2020), A European Strategy for Data

DATA SHARING GOES THROUGH FOUR CHANNELS, INVOLVING A DIVERSITY OF ACTORS

EXPERT POSITION 4 / **Stéphane Audoynaud is the deputy managing director of Port Adhoc.** Port Adhoc is a company dedicated to the development, management and operation of marinas in Europe, with 10 ports owned or managed (dry and floating) covering different navigation basins and totaling approximately 8,600 places.

"In the infrastructure industry, the size and range of data sets vary a lot. In the face of the power of GAFAs, infrastructure stakeholders have to build and reinforce their data management capacities to acquire leadership in this field. As far as Port Adhoc is concerned, we position ourselves as a breakthrough player: We are building a data management system, based on sensors and softwares we are creating, in order to develop advanced digital solutions.

In 2019, Port Adhoc developed a new commercial management platform (VEGA), designed to digitalize customer relations and offer new services in line with current consumer trends. This platform is expected to be the new digital gateway to the tourism ecosystem around ports. One of the major challenges is to identify the most relevant data so as to prioritize capacity building."

PORT ADHOC
LA NOUVELLE PLAISANCE

EXPERT POSITION 5 / **Stéphane Caine is the CEO of Proxiserve,** a leading player in the French market of smart metering and home services.

“The digitalization of a service company is a great opportunity to grow, delivering new services with more added value. It is also a solution for drastically improving the productivity and the efficiency of operations.

In order to keep our competitive edge regarding data, we have to continuously look for the hidden value behind data.

For example, when Enedis published data consumption for free, we did not lose customers because we offered them advanced treatment of their data, with added value.”

Proxiserve

THE INFRASTRUCTURE DATA VALUE CHAIN

The **monetization of data** in the infrastructure sector relies on a specific value chain: data must undergo different operations from collection to final use.
As an illustration, the Infrastructure 4.0 data value chain can be represented as in Figure 12 below.

Data acquisition plays a key role as it provides valuable data that is converted into a digital signal and helps **monitoring the infrastructure asset.**

The next stage of the value chain is to transform the data into information, with additional value, in order to control the operation of the asset and carry-out diagnoses to improve its performance.

This process requires "data lave-linge," which consists in augmenting each piece of data with informative tags but can only be done to a limited amount of data. Data labeling is particularly important for machine learning (especially supervised learning), in which data is labeled for classification to provide a learning basis for data processing.

The knowledge stage is the application / monetization of this data, for predictive maintenance (prognostics) and robotization (autonomics).

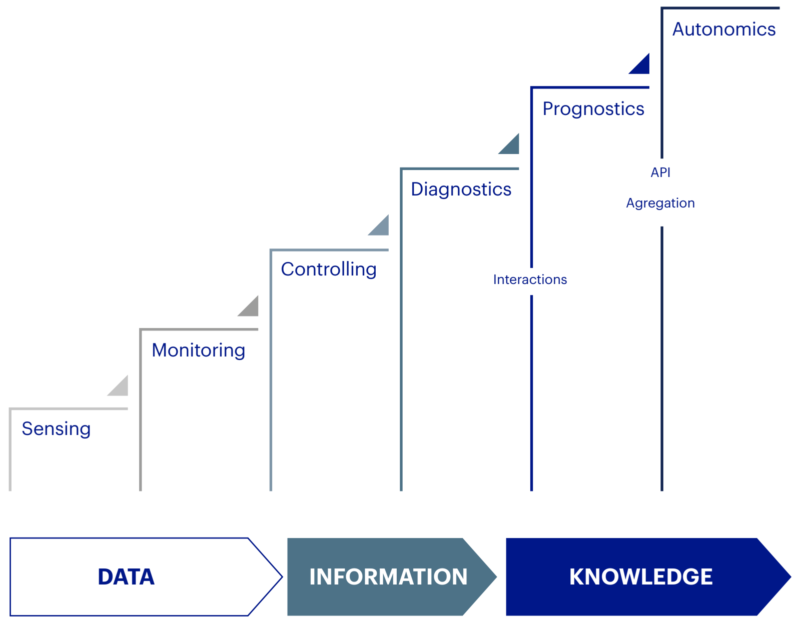
With the creation of a European market for industrial data, all these stages will be enriched with external data (from other asset classes, competitors, of clients).

THE VARIOUS FORMS OF MONETIZATION OF DATA

Data is key for creating incremental value in the infrastructure sector through:

→ **Optimization:** data can help to improve existing process and reduce costs, in particular administrative costs (robotics for low added-value tasks), energy costs (smart metering), construction costs (BIM) or maintenance costs (sensors associated with IoT, drones).

FIGURE 12
THE INFRASTRUCTURE 4.0 DATA VALUE CHAIN
Source: Henri Isaac for Altermind



THE MONETIZATION OF DATA CAN TAKE SEVERAL FORMS, DEPENDING ON THE WAY DATA IS EXPLOITED

EXPERT POSITION 6 / **Martin d'Argenlieu is the head of strategic projects, Olympique de Marseille (former general manager of Arema),** the company operating the Orange Vélodrome.

"Following our partnership with Orange, we have invested a lot in the digitalization of the stadium in order to become the first connected stadium in France. We have optimized our process. For instance, we have better control of energy loss, which contributes to reducing both our costs and our carbon footprint.

We have also improved our value proposition for spectators with "click and collect" services for food and beverages. One of our priorities is now to continue to improve access control using smart technologies. The deployment of 1,000 wifi antennas in the stadium will also help us offer new services to our clients. We are planning to install 5G by 2021."

All infrastructure assets, whatever their size, can implement such initiatives. For instance, the A28 Motorway (ALIS) has recently created a document management system (DMS) to track and store documents in order to reduce paper (purchase orders, expense account, etc.) and a geographic information system (GIS) accessible to service providers to visualize the roadway structure and used by employees as a management tool;

→ **Innovation,** in order to increase the existing value for clients: digitalization can help to improve the client experience, with more personalized, simpler and smoother services;

→ **Transformation,** enabling the creation of new value proposition for clients.

The monetization of data may be:

→ **Internal** when it is deployed for the company or **external** when it is increased by or deployed for third parties;

→ **Direct** if it is based on the company's data without requiring any specific processing (cleaning, aggregation, anonymization, hashing, etc.) or **indirect,** which is more like selling information, i.e. structured data put into context, than the data itself.

In this context, **four main business models** should be distinguished for the monetization of data in the infrastructure sector, as represented in Figure 13 below.

When they share their data with others, companies have to determine a **data valuation strategy** among several possibilities: the market approach, based on the market value of data; the cost plus approach, based on the minimum value to cover costs and generate a margin; and the revenue approach, based on the incremental value potentially generated by consumers through data.

FIGURE 13
THE FOUR DATA BUSINESS MODELS

Source: Henri Isaac for Altermind

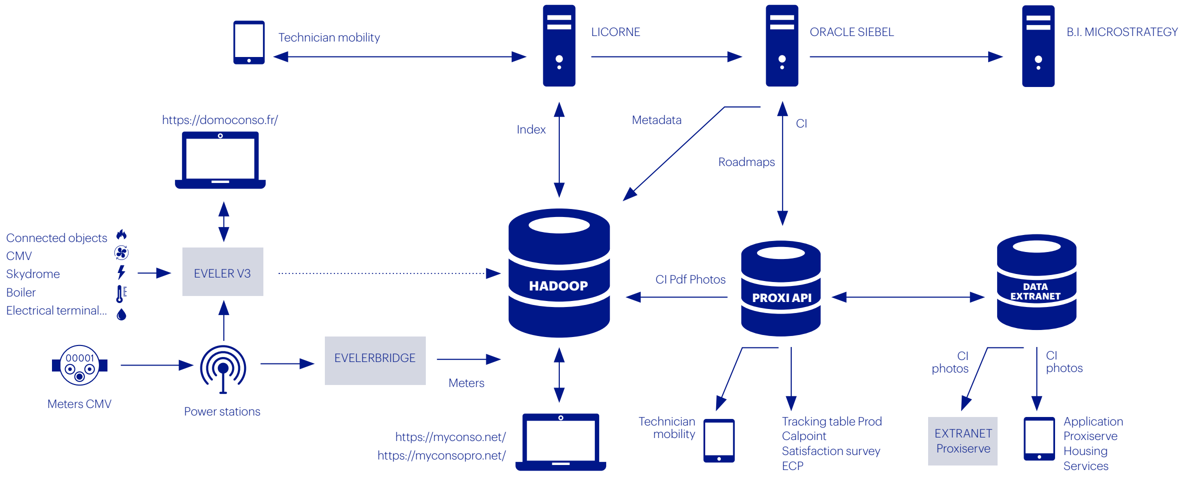
	DIRECT (B2C / B2B)	INDIRECT (B2B)
INTERNAL	**Optimization** – Cost reduction – Process Improvement – New services	**Data as a service** – Provision of raw, segmented or restated data to third parties
PARTNERSHIP	**Enhanced services** (by or for third parties) – Creation of services with third parties based on data – Creation of services for third parties based on data	**Data pooling** – Data aggregation (volume, richness, diversity) – Sales (audiences, segments)

CASE STUDY 5 - PROXISERVE

Proxiserve is a leading player in the French market of smart metering and energy services. It provides installation, maintenance, and sub-metering services for heating and water equipment in joint properties and public collective housing in France. Proxiserve also develops other businesses: it installs and maintains electric vehicle charging stations; it provides energy solutions–electricity supply, sub-metering, and billing services–to office buildings, hotels, and logistics platforms. Proxiserve has engaged its digitalization for more than ten years, with two main objectives: 1/ provide new connected services to its customers in order to differentiate from competitors, increase client retention and offer new services with more added value; 2/ significantly improve the efficiency of its operations in order to improve simultaneously its productivity and quality of services. *"We process and industrialize our services through digitalization in order to improve productivity and quality"* (S. Caine). The digitalization of Proxiserve has been built around its data lake, using the open-source software framework Hadoop (Figure 14).
All the data generated by its connected devices (controlled mechanical ventilation (CMV), boilers, charging stations, etc.), by their sales force (housing topics, contractual data) or by their technicians (certificates of intervention, pictures, etc.) go into this data lake. This data can be structured or not.

FIGURE 14
PROXISERVE'S IOT AND BIG DATA ARCHITECTURE

Source: Proxiserve



BASED ON THIS DATA, PROXISERVE HAS DEVELOPED VARIOUS APPLICATIONS:

⟼ **Real-time productivity monitoring:** all technicians are equipped with a digital device recording their interventions. The bonus system of the technicians is directly linked to this monitoring, on a monthly-basis. An AI application has been developed to identify irregularities in the planning or implementation of the interventions. As a result, Proxiserve's productivity has been rising.

⟼ **Extranet** for Proxiserve's clients, enabling them to access their contractual data and track-record;

⟼ **Remote control of smart phones**, in order to help its customers to repair their equipment themselves, which has positive impacts on costs optimization but also on customer experience;

⟼ **Predictive maintenance** of connected equipment, such as CMV;

⟼ **Monitoring of energy consumption** (in particular for large industrial customers) and water consumption (to identify leaks, for instance).

EXPERT POSITION 7 / **Serge Clemente is the CEO of Indigo,** the world leader in parking and individual mobility.

"The digitalization strategy of Indigo relies on four main pillars:

⟼ **PROCESS IMPROVEMENT:** this can be achieved notably by the automation of low added-value tasks;

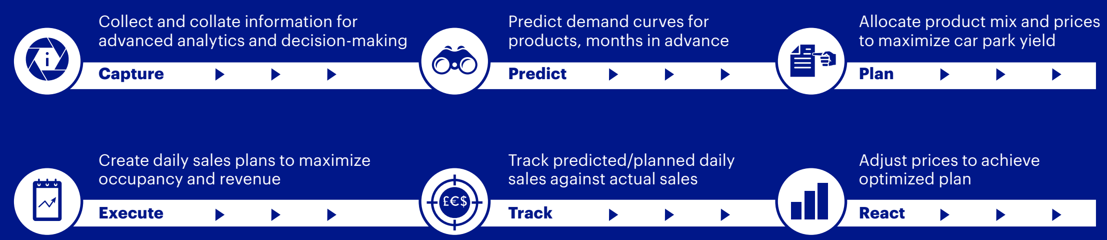
⟼ **CLIENT JOURNEY:** digitalization plays a major role in simplifying the journey of the end-user, with contactless system or license plate recognition;

⟼ **BUSINESS INTELLIGENCE:** though data, business intelligence aims at gaining greater insight of our current and future customers, maximizing and generating incremental revenue and driving efficiencies across all departments (Figure 15). Business intelligence has been particularly efficient in our Toronto Pearson parking, where we have increased our revenues by 3% last year by improving our knowledge of our clients' habits (depending on weather, congestion, etc.) and pushing offers accordingly;

⟼ **MONETIZATION OF THE PARKING INFRASTRUCTURE:** we are adapting our parking infrastructure in order to provide enhanced services, such as last-mile logistics, car sharing, EV charging, etc."

FIGURE 15
INDIGO'S REVENUE MANAGEMENT PROCESS OBJECTIVE

Source: Indigo



INDIGO GROUP

KEY TAKEAWAYS

The 4th industrial revolution is both a digitalization process and a cultural evolution.
The promises of digital infrastructure require profound changes in order to put in place a relevant data governance and skills set within organizations, improve relationships with public authorities and tackle societal / ethical issues.

KEY SUCCESS FACTORS OF INFRASTRUCTURE 4.0

IMPLEMENTING DATA GOVERNANCE WITHIN ORGANIZATIONS: A CHALLENGING PROJECT[36]

Most data will often need to be reprocessed to ensure its quality. Gartner Group identified 122 organizations in Europe and the United States that together had lost more than $1.2 trillion due to data quality issues.

However, far from being a purely technical issue, data quality can only be achieved and maintained over time through the involvement of various stakeholders who manage data within an organization. This organizational issue therefore requires data governance.

Such an approach must ensure data is (Figure 16):

⟼ **Accessible** regardless of its format or source;

⟼ **Available** to users and applications in a timely manner, regardless of the location or mode of use;

⟼ **Reliable,** complete and accurate;

⟼ **Consistent** across systems and processes;

⟼ **Secure,** complying with cybersecurity and privacy standards.

As illustrated by Figure 17, successful **data governance** within an organization is a collaborative process involving several levels:

⟼ **Strategic:** Ability to define business models that integrate data as a central resource in the value-creation process;

⟼ **Organizational:** Ability to organize resources and skills effectively;

⟼ **Operational:** Ability to manage business units and to articulate their capabilities with a view to creating value;

⟼ **Technological:** Ability to identify and operate the most effective technical platforms and resources.

Beyond the acquisition of such capacities, the main organizational issue is to **integrate all levels into the decision-making process within multidisciplinary teams, at all levels of the organization.** The organizational design is thus critical to gain a real competitive advantage through the implementation of a data-driven business model.

Designing comprehensive / holistic data governance is complex and involves a gradual approach to ease acculturation and ensure a rise in competence. Indeed, data governance requires the right skills set (technical and commercial / operational tools) in order to maximize adoption and usage.

⟶

DATA GOVERNANCE IS BASED ON A COLLABORATIVE APPROACH AT ALL LEVELS OF THE ORGANIZATION

(36) Source: Henri Isaac, Workshop 4

FIGURE 16
DATA QUALITY
Source: Henri Isaac for Altermind

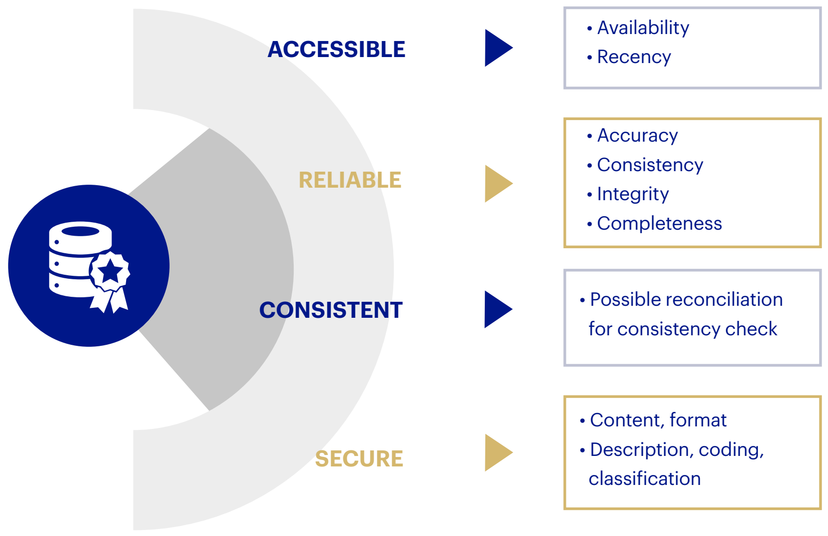
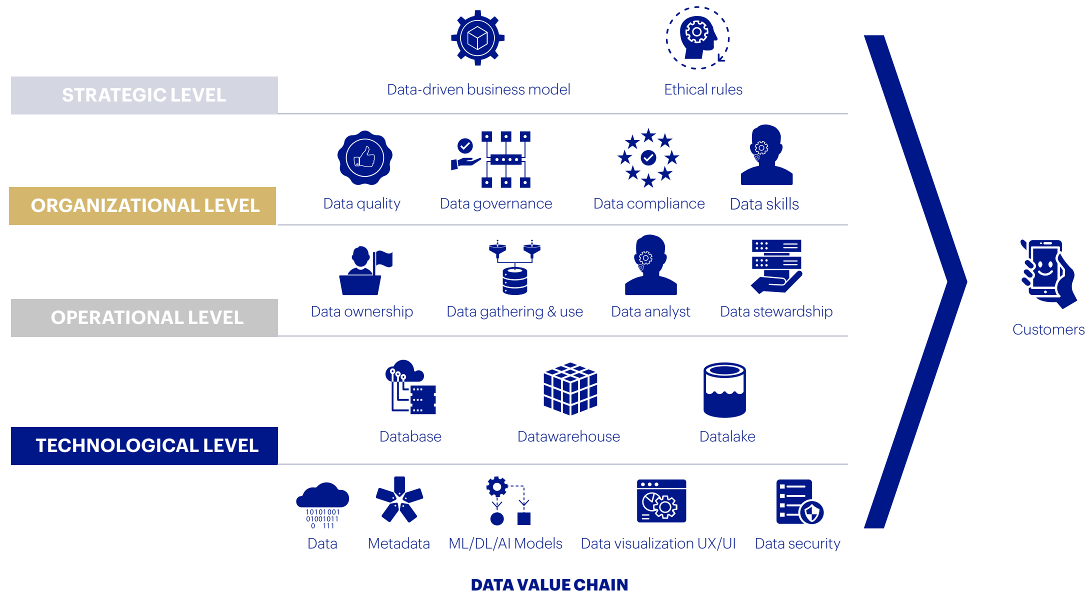


FIGURE 17
DATA GOVERNANCE
Source: Henri Isaac for Altermind



THE NEED FOR A MORE FLEXIBLE CONTRACTUAL AND REGULATORY ENVIRONMENT

One of the main obstacles to the digitalization of infrastructure is the rigid regulatory environment, which includes the manner in which public procurement is managed, and the set of rules governing infrastructure assets and related services.

Public procurement and regulations are lagging behind in embracing digitalization[37].

Digital infrastructure should be considered as an opportunity by public authorities, involving profound changes[38]:

⟶ Digital tools can scale up public infrastructure as never before. Governments can benefit from **scale and network effects** to share data, storage and processing abilities;

⟶ With the emergence of new players and business models, governments are no longer the sole provider of public services. **New forms of collaboration with the private sector** have emerged to solve social and economic issues.

Therefore, governments can rely on two levers to foster digital infrastructure: **public contracts and state regulations.**

The implementation of **flexible procedures in public contracts** is necessary. Contractual practices need to change and to make the most of existing mechanisms favorable to innovation, such as the innovation partnership.

"Smarter" regulation will also be essential to:

⟶ **Allow the deployment of new services:** As explained by the Center on Regulation in Europe (CERRE), *"given the increasingly rapid and uncertain evolution of markets, regulation should be principle-based to adapt more easily as technologies and markets change.*[39]*"* These principle-based rules should be complemented by soft-law instruments, co-constructed with all stakeholders, and clarified through their implementation by administrative and independent regulatory authorities, and if needed, by the legal system;

⟶ **Motivate and better protect innovations:** According to the World Economic Forum, this can be achieved by increasing access to open data and facilitating access to Intellectual Property Rights (IPRs)[40].

THE NEED FOR ADDRESSING KEY SOCIETAL ISSUES

Digitalization is profoundly and unevenly affecting businesses, governments, people and the environment. It offers **value-creating opportunities but also raises legitimate concerns among a growing number of actors.** These concerns should be addressed by the infrastructure sector stakeholders in order to ensure the success of digitalization.

◇ Digitalization and working conditions

Past major technological innovations resulted in substantial job losses in the short term. In some cases, entire industries were substantially altered. Similarly, digitalization has led to fears that computers and robots will replace human labor.

As a matter of fact, digitalization is already **reducing demand for low-level tasks while increasing demand for problem-solving and interpersonal skills.** It is also reshaping the way work is organize through the emergence of a "platform economy" calling for more flexibility from workers (i.e. self-employment, temporary hiring)[41].

Digitalization has a profound impact on the skills set required for organizations to thrive. In a context where horizontal / desiloed communications are key to foster agility and create value, digitalization has sharpened the generational divide.

In the case of infrastructure, the upskilling and reskilling of less qualified workers and technicians are economic as well as ethical issues.

◇ Digitalization and carbon-neutral trajectory

The increase in global economic activity raises growing environmental risks and contributes to higher levels of carbon emissions. According to OECD data, "the historic trend holds that for every 1% increase in global GDP, CO_2 emissions have risen by approximately 0.5% and resource intensity by 0.4%.[42]"

With the exponential increase in digital use and the growing production of **digital devices, the digital share of greenhouse gas emissions** has increased.

However, digitalization also helps **to replace more carbon-intensive practices.** In this respect, key data from a study realized jointly by GSMA and Carbon Trust indicates that, in 2018, mobile communication technologies helped to avoid approximately 2.135 million tons of CO_2[43].

From this perspective, if digitalization is supported through effective public policies, it can become a vehicle for sustainable development by[44]:

⟶ **Improving energy efficiency** and reducing gas as well as electricity consumption for buildings;

⟶ **Enhancing vehicle fuel efficiency** and facilitating the use of charging points for electric vehicles;

⟶ **Reducing the overall level of inventory** and reducing energy use for manufacturing activities;

⟶ **Monitoring electricity demand** and improving distribution efficiency for energy purposes.

In such a scenario, according to the World Economic Forum, the development of intelligent technologies would make it possible to avoid 26 billion tons of carbon emissions by 2030[45].

◇ Digitalization and social contract

The advent of digital infrastructure and practices challenges current frameworks that **govern privacy and security[46].** It may spark fears among users that their personal data is being collected without their knowledge by private actors, operating on platforms, and by public authorities, or that their rights to individuality and free speech are being undermined because of new technologies' potential for mass surveillance.

Yet, digitalization has also demonstrated its **ability to rebuild trust:** social media and user-generated platforms have increased transparency and reduced information asymmetries. To answer people's fears, proper protections should be put in place and complied with. **The progressive integration of blockchain into digital processes** could further help to anonymize and secure data processing and storage[47].

All in all, there is a trade-off to make between data privacy and data fairness: although there are many criteria to ensure fairness, they are not always compatible with each other (sex, minorities, etc.).

These societal fears should be taken into account by infrastructure managers in order to avoid mistrust.

(37) World Economic Forum (2019), Transforming Infrastructure: Frameworks for Bringing the 4th Industrial Revolution to Infrastructure
(38) OECD (2017), Going Digital: Making the transformation work for growth and well-being
(39) CERRE White Paper 2019-2024 (2019), Ambitions for Europe 2024
(40) World Economic Forum (2019), Transforming Infrastructure: Frameworks for Bringing the 4th Industrial Revolution to Infrastructure rethinking digital, energy and mobility regulation
(41) OECD (2017), Going Digital: Making the transformation work for growth and well-being, Ibid.
(42) GSMA (2019), The Enablement Effect: the impact of mobile communication technologies on carbon emissions reductions
(43) Ibid.
(44) World Economic Forum (2020), Understanding the impact of digitalization on society
(46) Ibid.
(47) Wavestone (2017), La vie privée à l'ère du numérique : au-delà de la conformité

⟶

DIGITALIZATION OFFERS VALUE-CREATING OPPORTUNITIES BUT RAISES CRUCIAL ISSUES FOR THE SOCIETY

EXPERT POSITION 8 / **Serge Clemente is the CEO of Indigo,** the world leader in parking and individual mobility.

"Indigo has taken many initiatives to innovate but we have faced two main constraints.

First, the concession framework is very rigid and strict: we need municipalities to approve any new service we put in place and it takes time and energy.

Second, regulations are often not adapted to innovative services. For instance, we have not deployed EV charging points as fast as we wished because of some regulations designed before such services existed, such as fire regulations."

INDIGO GROUP

PART III:
A NEW HORIZON FOR INFRASTRUCTURE STAKEHOLDERS

The emergence of the 4th industrial revolution connects physical assets to digital ones, fosters a more collaborative approach and enables them to be closer to clients. To fulfill their potential, these transformations have to be integrated by all infrastructure stakeholders, in particular investors.

KEY TAKEAWAYS

In the Infrastructure 4.0 era, infrastructures are not only physical, but also integrate advanced technology, which makes them more adaptable to different environments and helps to deliver more effective services.

Infrastructure assets should now be conceived as transversal assets, especially in urban environments, where platforms are key drivers of green, smart and sustainable cities.

Digitalization opens new opportunities to better answer the needs of the client, through distributed and light assets instead of centralized and heavy assets.

These trends have major consequences for investors.

INFRASTRUCTURE 4.0: THE RESHAPING OF INFRASTRUCTURE & INFRASTRUCTURE INVESTMENT

As illustrated by Figure 18, digitalization will reshape infrastructure, from **physical assets to stacked assets, from sectoral assets to desiloed assets and from centralized assets to distributed assets.**

FROM PHYSICAL ASSETS TO STACKED ASSETS

In the Infrastructure 4.0 era, infrastructure is not only a physical asset anymore, it also integrates advanced technology (Figure 19). The foundation of infrastructure–and of the related services–remains the physical asset (water pipeline, electricity or gas network, airport, roads, buildings, etc.). However, above this **physical layer,** additional technological layers become part of the infrastructure:

- **The sensors' layer,** which enables data to be collected;
- **The network layer,** which ensures the connectivity of infrastructures;
- **The data and support layer,** which secures and manages data (in particular with cloud computing to store and process data and AI to optimize decisions);
- **The application layer,** which may have various purposes (transport, energy, climate change, e-government, healthcare, etc.) and may use user-friendly interfaces for consumers, creating more opportunities for people to engage with the infrastructure asset.

By integrating advanced technology into infrastructure, it can become more flexible and adaptable to different environments or events and deliver more effective services. Digitalization allows services to adapt themselves and go beyond the usual classic offers.

In this context, **infrastructure managers** should follow a **"holistic" approach,** taking into account, from the outset of any project, not only the physical characteristics of infrastructure assets but also the technology embedded in it, with a focus on its applications and the services delivered to users.
Street furniture provides a good illustration of the transformations underway:

- With **smart public lighting,** thanks to IoT and AI, it is possible to modulate the lighting of the street according to weather conditions, the time of day, the neighborhood, the presence of people or vehicles, which in turn extends the life of the lamps, saves energy, etc.; In addition, because the lighting system is connected to a network, it is possible to use street lighting for other services by equipping them with sensors to monitor and manage traffic, parking, air pollution, air levels, water levels, etc. This information can be accessible on the citizens' cell phones and influence their behavior (go for a walk if the air quality is good, avoid using a car in case of bad weather conditions or traffic jams);
- Following the same logic, **other street furniture** (traffic lights, traffic signs,

INFRASTRUCTURES ARE BASED ON A PHYSICAL FOUNDATION, BUT ALSO INTEGRATE DIGITAL TECHNOLOGIES

[48] Inspired by FG-SCC, I.T.U.T. (2015), Setting the framework for an ICT architecture of a smart sustainable city. Focus Group Technical Specifications, 49

FIGURE 18
DIGITAL INFRASTRUCTURE
Source: Altermind

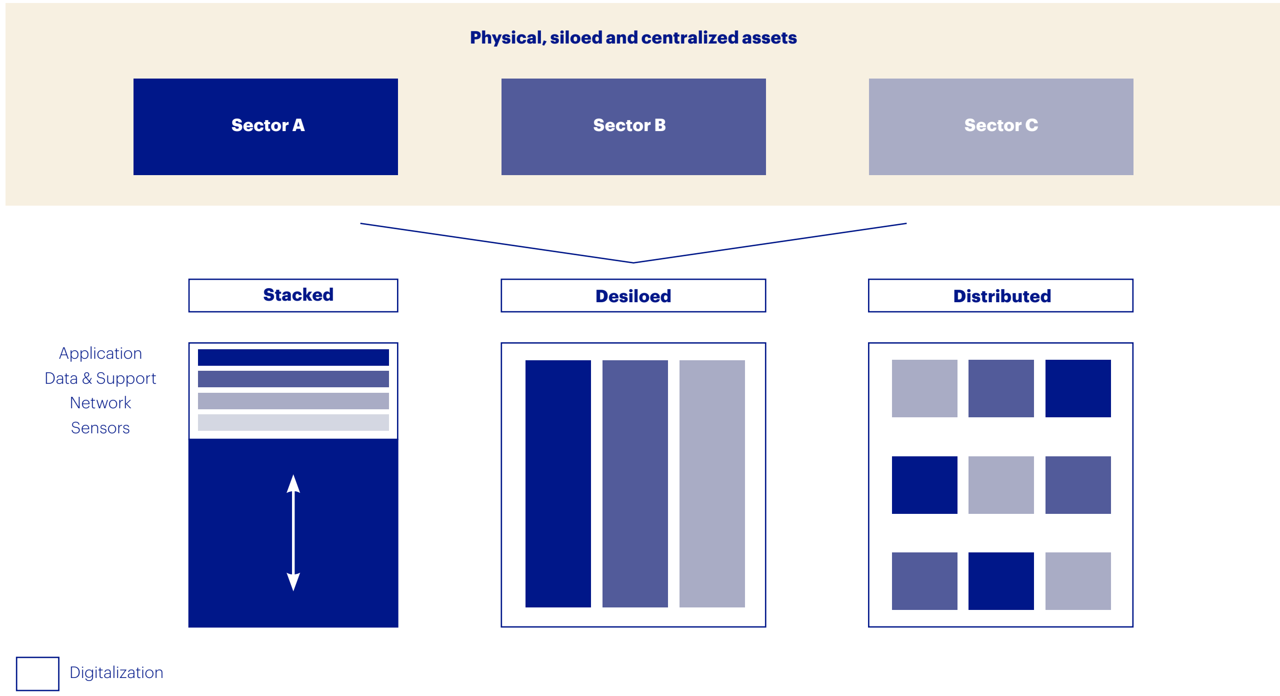
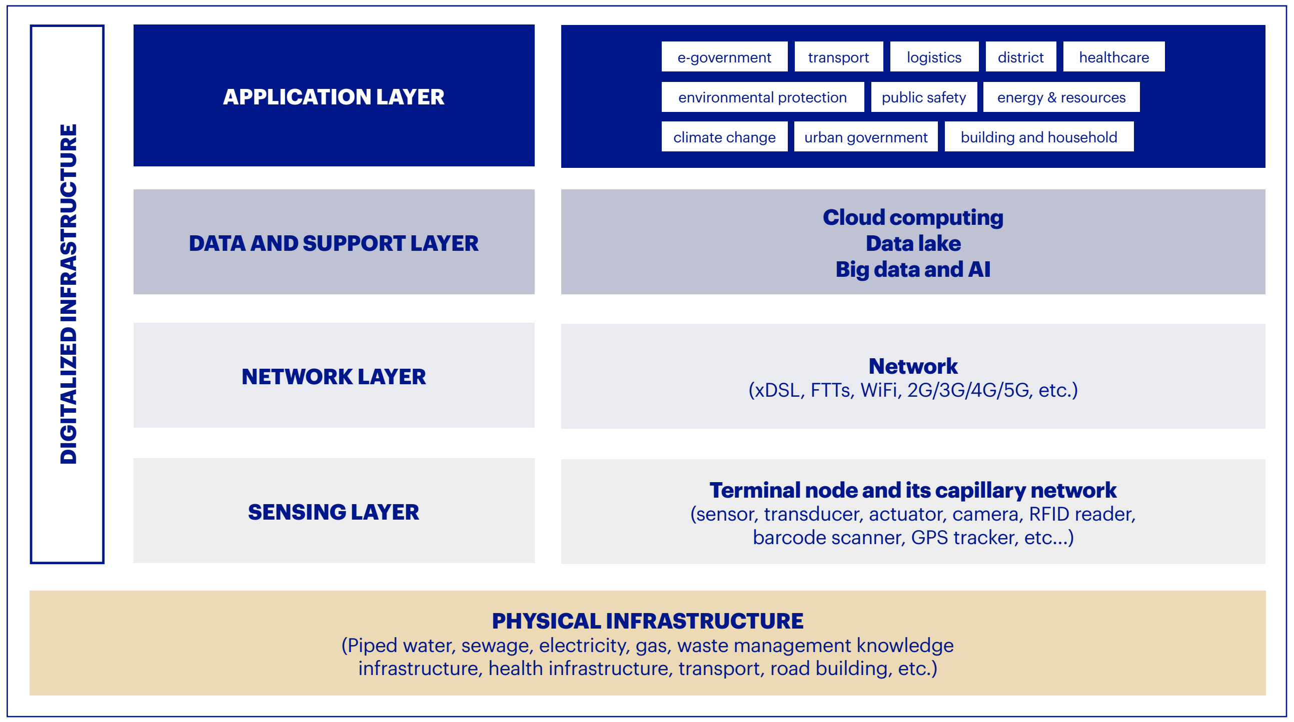
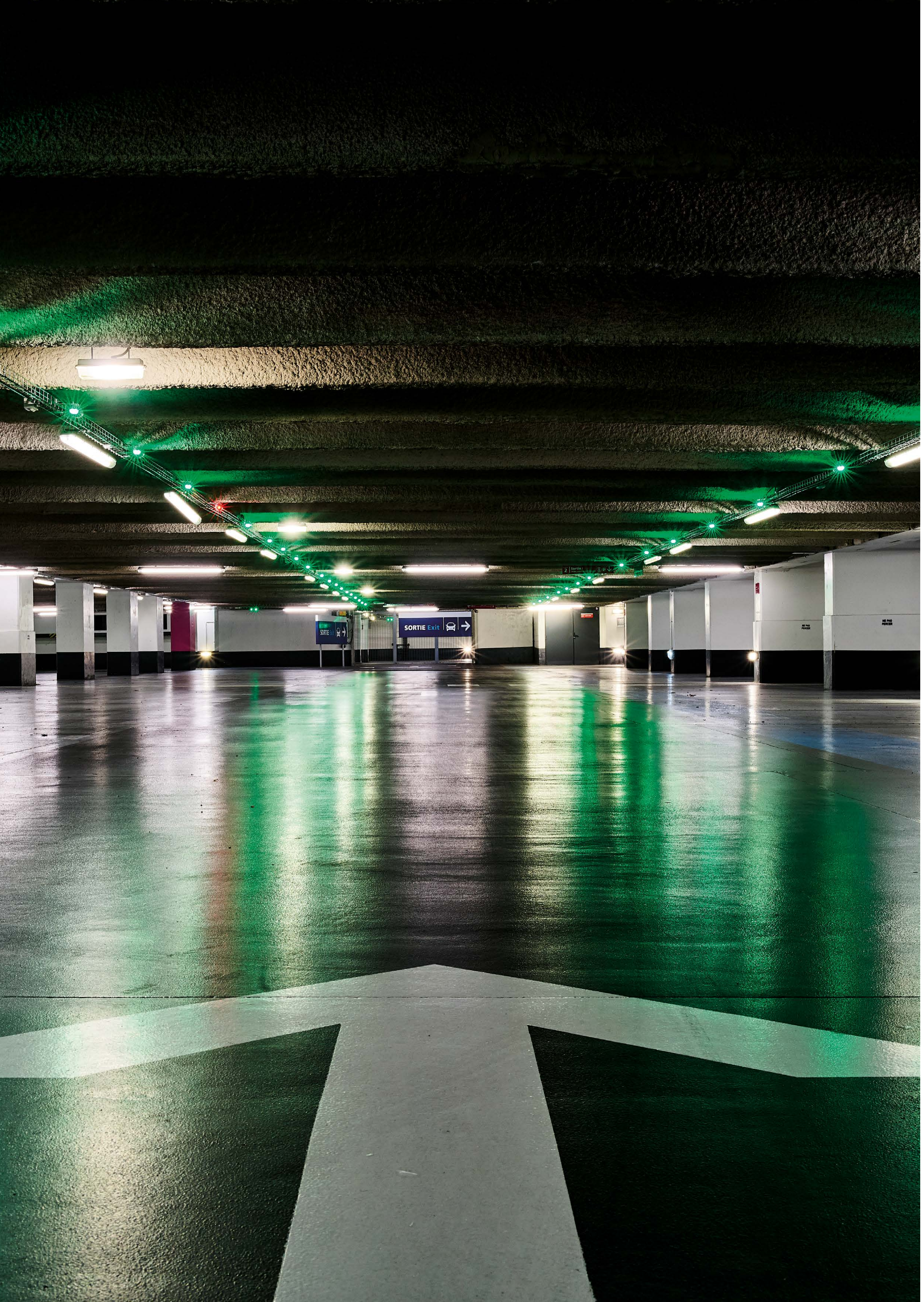


FIGURE 19
THE STACKED INFRASTRUCTURE
Source: Altermind[48]





CASE STUDY 6 – INDIGO

Indigo brings together several businesses: off-street parking, on-street parking, individual mobility, digital and services. With more than 23,000 employees, Indigo manages over 5,600 car parks, more than 2.3 million parking spaces and 3,000km of on-street parking across over 750 cities in 12 countries.

Indigo builds, finances and operates customized and increasingly **intelligent parking solutions.** In parallel, its parking is increasingly becoming a platform for mobility, energy and logistics.

New trends in mobility require parking infrastructures to adapt and offer additional services to simply being a location where cars can be left. The need to **optimize use in limited spaces of high-density urban areas** and the impetus to conceive sustainable solutions further reinforce the need for additional services.

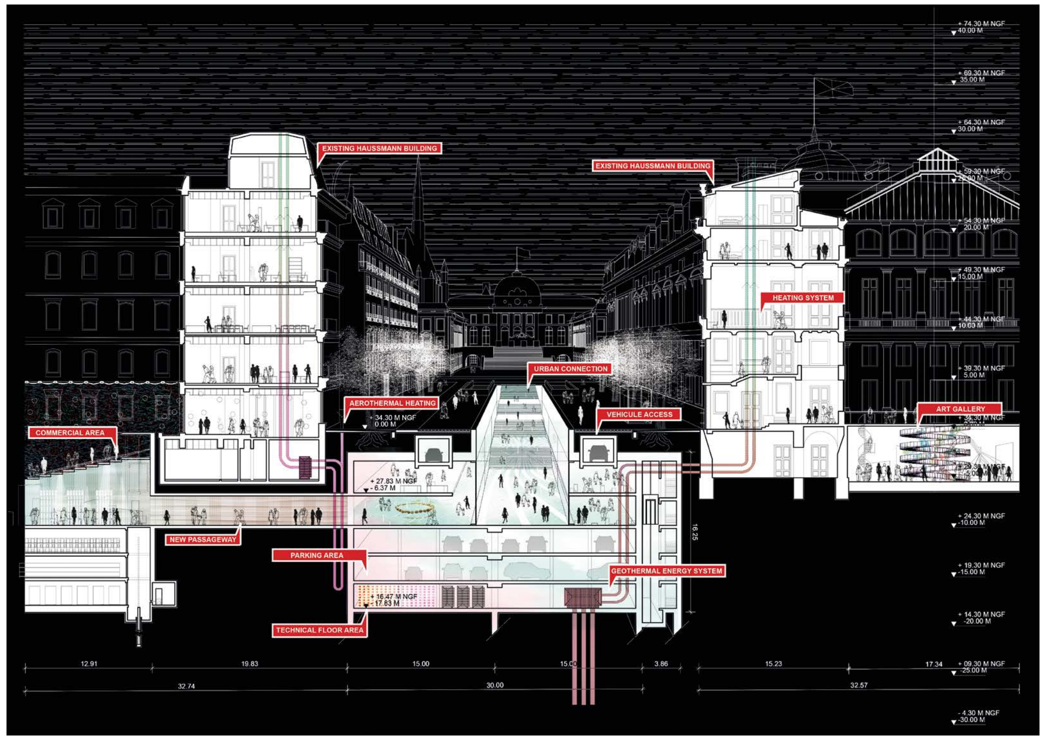
Existing underground infrastructures are sometimes considered as under-used and ready to be reconverted, and are therefore particularly useful in meeting these new challenges.

From this perspective, Indigo has conceived the "**Parking of the Future**" with the architect Dominique Perrault, which envisions that car parks will become a **site of vertical and horizontal integration,** as they will open up access to underground resources and link transport and businesses (Figure 20).

FIGURE20

INDIGO'S PARKING OF THE FUTURE: PARIS TOMORROW

Source: Indigo



Consequently, the Indigo Group relies on this approach to build the cities of tomorrow by:

- Creating an 800m² logistics platform in a car park in Paris: this is a logistics facility that encourages a rapid turnover of goods by minimizing storage time;
- Building a vegetable garden on the roof of a car park in Meaux: this involves refurbishing the rooftop terrace to plant a dozen bushes, and six eco-responsible planters;
- Installing Amazon lockers in the car park of Strasbourg Wodli: the objective is to improve the comfort of users;
- Transforming car parks in Colombia into football fields or fast-food areas on weekends: this aims at contributing to the dynamism and prosperity of downtown Bogotá.

bus shelters, automatic public toilet, clocks, public drinking fountains, advertising columns, etc.) can also be equipped with sensors and shelter applications providing them with new functions (cell phone charging stations, etc.) without taking up more space in the public space.

FROM SILOED ASSETS TO TRANSVERSAL ASSETS AND PLATFORMS

Historically, infrastructure assets have been built and managed sectorally, reflecting the silo-type organization of public services. Digitalization turns around this logic: infrastructure assets should now be conceived as **transversal assets, requiring the cooperation of various stakeholders.** This is particularly true in the urban environment, where platforms are key drivers of smart and sustainable cities.

◇ The transversal logic of digitalization
Digitalization goes with disruption and blurred boundaries: New players appear and compete with "traditional" service operators, consumers are becoming producers in a sharing economy perspective, mobility is now based on the complementarity between public transportation and private on-demand services, whereas urban lighting equipment is used for traffic management and safety.

In this context, the purely sectoral and vertical approach is disappearing in favor of a **cross-sector and transversal approach,** through the integrated management of networks, the interconnection or even the mutualization of infrastructure assets and services.

Infrastructure managers are more and more aware of this trend, which has two main consequences:

⟼ **Collaboration** with other stakeholders becomes critical to innovate. For instance, SNCF (railway sector) has worked with EDF (electricity sector) to rely on the most effective technology to connect its electrical installations. It has also concluded partnerships with telco operators to cross-benefit from parallel infrastructure, by renting its infrastructure to bury optical fibers all along the track;

⟼ **Infrastructures are becoming** collaborative business model **platforms** that allow multiple participants (producers and consumers) to connect, interact with each other, create and exchange value.

◇ Platforms and smart cities[49]
Cities should be understood as **ecosystems of ecosystems.** There are at least a hundred principal ecosystems in a city, defined by districts (central business district, housing districts, technology districts, port areas, etc.), activities (finance, construction, education, service sectors, trade and wholesale, etc.) and utilities (transportation, energy provision, water provision, waste management, etc.).

Smart cities aim at managing this complex structure of the cities through digitalization. However, smart cities have inherited the vertical structure of cities. It is therefore critical to ensure the **interoperability of smart city services.**
From this perspective, **platforms are the most promising tools:** they offer externalities, user engagement and awareness, which in turn enable multiple forms of innovation, disruptive, social, eco-innovation.
Platforms generate network effects through three levers:

⟼ **Externalities through co-creation of value,** opening up opportunities, and providing a "lift" to third party practice;

⟼ **Engagement,** which is the commitment made by members of a community to participate in activities that fulfill objectives. Engagement platforms are crafted through the logic of social innovation: they contribute to creating an active community around a topic of concern and incentivize members of the community to accomplish actions for social innovation;

⟼ **Awareness,** by collecting information through mapping and information dissemination, fosters protective environments, causes behavior change and creates mechanisms for direct intervention in case a risk is detected.

This triggers various types of innovations (Figure 21).

Platforms are especially relevant for smart transport. For instance, for freight, heavy users of transportation services used to invest in transportation assets (trucks or rail) or hire a carrier or a third-party logistics operator.

(49) Source: Nicos Komninos, Workshop 3
(50) Prevost, C. (2018), "The sharing economy: six disruptions on the transportation ecosystem," Freightwaves
(51) Glachant, J.-M. (2019), New business models in the electricity sector, European University Institute Working Papers, RSCAS 2019/44

FIGURE 21
INNOVATIONS THROUGH PLATFORMS

Source: Nicos Komninos for Altermind

AS SHARED SPACES Disruptive innovations for growth	AS INFORMATION SPACES Eco-innovations for sustainability	AS ENGAGEMENT SPACES Social innovations for living
Sharing economy– New growth– smart growth • Business growth platforms • Business over Business • P2P production, demand driven	**Social networks, real time alert** • Behavior adaptation to external conditions driven • Awareness and solutions about the environment, pollution, energy saving, CO_2 emissions, climate change	**Social innovation and citizen non-profit networks** • Mapping and motivation for participation and change • Real-time safety and security systems in the public space of cities

However, with the appearance of platforms, new collaborative opportunities emerge, which favor coordination for regional parcel carriers, real-time market place for long-haul trucking, multimodality (thanks to the coordination of handoffs between carriers at intermediate way points for a point to point delivery model), crowdsourcing (for warehouse for instance) or safety (through crowdsourced data on traffic or weather conditions)[50].

FROM CENTRALIZED ASSETS TO DISTRIBUTED ASSETS

Many infrastructure assets, such as telecom, electricity or rail networks, have historically been conceived and operated nationally, in a centralized perspective, by **national public monopolies.**

The **introduction of competition has marked a first break** with this historical situation, with new players participating in the telco sector, the production and provision of electricity or railway services.
The digitalization of infrastructure will accelerate this trend. Indeed, it opens new opportunities to better answer the needs of clients, through light and distributed instead of heavy and centralized assets.
For instance, new **"autonomous electrical territories"** are being developed, which depart from the unilateral control that electricity grids and their system operators have always kept on exchange schemes – and challenge their business model and regulation. This refers in particular to[51]:

⟼ **"Behind the meter"** (BTM) smart management systems: individual units, on the consumption side, can now program and coordinate their own generation, own storage, and the various load profiles of their various consumption devices;

⟼ **"Micro-grids":** Smart consumption units can act as autonomous "mini-systems," such as electric cars or "zero net consumption" buildings.

The same trend is also developing in the telco sector. Among telco operators, new players have indeed appeared and positioned themselves as "local" operators, closer to their clients –public authorities (B2G) or companies (B2B)– as shown by the example of Axione.

This trend will be accelerated by 5G, which, coupled with machine learning, will enable the deployment of a largely decentralized computing structure for the benefit of the IoT, reorganizing the reality of everyday life (autonomous cars, voice assistants and sensors) and public space (smart cities, smart power grids, health networks, etc.). Data will be processed closer to its source through on-device AI, offering key benefits such as privacy, reliability and personalization.[52]

THE IMPACTS OF INFRASTRUCTURE 4.0 FOR INFRASTRUCTURE INVESTORS

The digitalization of infrastructure leads to profound changes in the way infrastructure assets should be defined, designed and operated. These changes will be accelerated by the **combination of growth and resilience objectives** which could follow the Covid-19 crisis.
Infrastructure stakeholders should be aware of these transformations and adapt their strategy accordingly. As we finalize this report, the prospect of a vaccine sometime through H1 2021 is becoming real. However, there is a wide consensus that some of the impacts of this unprecedented shock will, at least to some extent, be permanent.
For investors, Infrastructure 4.0 has four main implications (Figure 22):

- **The selection of investment opportunities:** Taking into account the consequences of the crisis and the dynamics of digitalization, investors should combine a "least regret strategy," focused on the most resilient assets, and a "brave new world strategy," identifying assets which offer the highest long-term value-creation potential;
- **Transaction structuring,** both from a financial and legal perspective, to reflect the polymorphic revenues, risks and time horizons provided by the digitalization of infrastructures;
- **Investment perimeter:** Infrastructure is not only a physical asset anymore and new business models based on digitalization (data-driven business models) are emerging. In this context investors should move-up the value chain to capture some of the added-value created by data;
- **The management of assets:** To exploit the opportunities created by digitalization, the management of infrastructure assets should contribute to adapting and upgrading existing infrastructure while controlling the risks arising from digitalization, both internal (technological obsolescence) and external (competition from new players).

WITH THE DIGITALIZATION OF INFRASTRUCTURES, THE NEEDS OF THE CLIENTS ARE NOW MET THROUGH DISTRIBUTED ASSETS

(52) Institut Montaigne (2020), 5G et Machine Learning : Changements de Paradigme, Regards croisés entre Gilles Babinet et Victor Storchan

FIGURE 22
INFRASTRUCTURE 4.0: INVESTMENT STRATEGIES IN THE POST-COVID-19 WORLD

Source: Altermind

	INFRASTRUCTURE PRE-COVID-19	INFRASTRUCTURE 4.0 IN A POST-COVID-19 WORLD
PREFERRED ASSETS	Long-term, stable, predictable cash-flows...	... with proven resilience and significant upside potential
TRANSACTION STRUCTURING	Project, non-recourse finance...	... toward hybrid financing (project, corporate)
INVESTMENT PERIMETER	Physical asset...	... and IP, talent
ASSET MANAGEMENT	Focus on maintenance	... and innovation

CASE STUDY 7 – AXIONE

Axione is a telecommunications operator created in 2003 that designs and deploys telecommunications infrastructures, in France and internationally, developing and enabling new digital uses. By the end of 2019, it was serving 6,500 French municipalities with broadband and 2,500 business areas with very high-speed broadband. The company has become a major player in the Public Initiative Networks market, with a market share of around 20%.According to Eric Jammaron, CEO of Axione, "In the telco sector, **the era of "big is beautiful" is over.** We observe that our clients – especially in the B2B activity– are departing from traditional solutions to create their own **private network.** This opens new opportunities, such as developing local networks of local data centers near industrial centers." This trend combines with the **platformization of infrastructure.** From this perspective, in June 2020, Axione and Vauban Infrastructure Partners announced the launch of a new platform (Vauban Infra Fibre) to address the challenge of local digitalization in France, which will consolidate existing or newly deployed infrastructure for the marketing of fiber networks to telco operators, in both urban and rural communities, as well as in medium density areas.

APPENDICES

APPENDIX 1: BIOGRAPHIES OF EXPERTS

LEADING ACADEMIC EXPERT:
PATRICE GEOFFRON

PATRICE GEOFFRON is presently interim president at the University of Paris-Dauphine and is a member of the "Cercle des Économistes." Founder of the Dauphine Economics Research Laboratory (LEDa), he now runs its energy-climate team, which coordinates various research chairs (notably the Climate Economics Chair created in 2010).
He is the editorial manager of the Economics and Policy of Energy and the Environment journals and the Journal of Management and Network Economics.
Patrice was a partner for ten years in an information technology consulting firm and has participated in numerous expert missions in the transport sector (SNCF, ADP, etc.). He is a member of the support team for the Citizen's Climate Convention.
Patrice is a senior advisor at Altermind.

DIGITAL ECONOMY EXPERT:
HENRI ISAAC

HENRI ISAAC holds a PhD in management sciences, and is an Associate Professor at the Paris-Dauphine University and the PSL Research University. As a specialist in information systems and digital economy, his research, at the frontier of the field of information systems and management, focuses on the effects of technologies on companies and their management.
Henri is head of the Telecommunications and Media Management Master's program and Chairman of the think tank "Renaissance numérique". He is a member of the "Conseil National du Numérique" (CNNum).
Henri is a senior advisor at Altermind.

LEGAL EXPERT:
ADRIEN BASDEVANT

ADRIEN BASDEVANT is an attorney at the Paris Bar, specializing in new technologies law. He defends and advises start-ups, large groups, and individuals on issues of fundamental freedoms and digital transformation. He particularly focuses on strategic and legal matters related to big data, cybercrime and innovation.
Adrien has also created the www.coupdata.fr platform, which analyzes the impact of technology on society, and has published "L'Empire des données" on the matter in 2018. He is a member of the "Conseil scientifique du Collège des Bernardins."
Adrien is a senior advisor at Altermind.

TRANSPORT AND ENERGY EXPERT:
GUILLAUME GAZAIGNES

GUILLAUME GAZAIGNES is a graduate engineer from the Ecole Nationale Supérieure d'Arts et Métiers and Centrale Lille.
He joined SNCF Réseau in 2008 as a project manager. He becomes Head of Innovation and Energy Research within the company in 2016. He was appointed Director of Innovation and CSR (Corporate Social Responsibility) at SNCF Logistics in 2018.

SMART CITY EXPERTS:
CHRISTINA KAKDERI AND NICOS KOMNINOS

CHRISTINA KAKDERI is an assistant professor at the School of Engineering, Aristotle University of Thessaloniki and a member of URENIO Research, a University Laboratory focusing on the design, development and governance of innovation ecosystems and intelligent cities.
She is a regional economist focusing on systems of innovation and smart innovation environments (national and regional innovation systems, technology policy, social networks, intelligent cities/districts). She has participated in numerous EU and nationally funded projects related to spatial development and innovation ecosystems and has authored many publications on smart cities and innovation strategies including Smart Cities in the Post-Algorithmic Era (eds.) (2019), Edward Elgar.

NICOS KOMNINOS is professor emeritus at the School of Engineering, Aristotle University of Thessaloniki and CEO of Intelspace Technologies, a company developing technologies and solutions for smart cities.
He has coordinated numerous research projects, participated in the design of science and technology parks, smart cities, and regional innovation strategies in most regions of Europe; member of the group of experts for the OECD innovation strategy; and assessor of research in the EU, Scandinavian countries, Asia and New Zealand.
He is author of 180 publications, including thirteen books on intelligent and smart cities, urban planning, innovation territories and strategies; editor, associate editor and member of the editorial board in twelve academic journals and co-editor of Elsevier's series on smart cities.

APPENDIX 2: LIST OF PARTICIPANTS AT THE WORKSHOPS

MARTIN D'ARGENLIEU (AREMA)

Martin d'Argenlieu is the head of strategic projects, Olympique de Marseille (former general manager of Arema), the company operating the Orange Vélodrome.

STÉPHANE AUDOYNAUD (PORT ADHOC)

Stéphane Audoynaud is the deputy managing director of Port Adhoc. Port Adhoc is a company dedicated to the development, management and operation of marinas in Europe.

STÉPHANE CAINE (PROXISERVE)

Stéphane Caine is the CEO of Proxiserve, a leading player in the French market of smart metering and home services.

GWENOLA CHAMBON (VAUBAN INFRASTRUCTURE PARTNERS)

Gwenola Chambon is a Managing Partner and Founding Partner of Vauban Infrastructure Partners.

SERGE CLEMENTE (INDIGO GROUP)

Serge Clemente is the CEO of Indigo, the world leader in parking and individual mobility.

MOUNIR CORM (VAUBAN INFRASTRUCTURE PARTNERS)

Mounir Corm is a Managing Partner and Founding Partner of Vauban Infrastructure Partners.

ARI KOPONEN (VAUBAN INFRASTRUCTURE PARTNERS)

Ari Koponen is a senior advisor to Vauban in Nordic countries and active Director on the Board of Loist Oy. Loiste is one of Finland's largest electricity suppliers, providing Finns with products and services that promote energy efficiency and energy savings.

FERNANDO LOZANO RUIZ (METRO MALAGA)

Fernando Lozano Ruiz is the director general of Metro Málaga, the light rail network of Malaga.

DIEGO MARIN GARCIA (ACCIONA)

Diego Marin Garcia is the managing director of Acciona Concesiones. Acciona is a Spanish company dedicated to the development and management of sustainable infrastructure and renewable energy.

PIERRE VANSTOFLEGATTE (BOUYGUES ENERGIES & SERVICES)

Pierre Vanstoflegatte is the CEO of the Bouygues Construction Energies & Services division. Bouygues Energies & Services provides services to optimize energy consumption.

APPENDIX 3: GLOSSARY

AI	Artificial Intelligence
AM	Additive Manufacturing
BIM	Building Information Modeling
B2B	Business-to-Business
B2C	Business to Consumer
CMV	Controlled Mechanical Vehicles
CCS	Connected Control Station
COP	Conference of Parties
COVID-19	Coronavirus disease 2019
CO2	Carbon Dioxide
CSP	Communication Service Provider
DCIS	Digitally Connected Infrastructure System
EDS	European Data Strategy
EU	European Union
EV	Electric Vehicles
ICT	Information and Communications Technology
IEA	International Energy Agency
GAFA	Google, Apple, Facebook and Amazon
G2B	Government-to-Business
G2G	Government-to-Government
GSMA	Global System for Mobile Communications
IoT	Internet of Things
IoV	Internet of Vehicles
IPR	Intellectual Property Rights
IT	Infrastructure and Technology
MaaS	Mobility as a Service
M&A	Mergers and Acquisitions
NIAC	National Infrastructure Advisory Council
OECD	Organization for Economic Co-operation and Development
PPP	Public-Private Partnership
PSI III	Public Sector Information Directive
PSD2	Revised Payment Services Directive
QR Code	Quick Response Code
RPA	Robotic Process Automation
R&D	Research and Development
SDG	Sustainable Development Goals
SNCF	French National Railway Company
UN	United Nations
VR/AR	Virtual Reality and Augmented Reality
WEF	World Economic Forum
WHO	World Health Organization
WTO	World Trade Organization
4G	Fourth Generation of Broadband Cellular Network Technology
5G	Fifth Generation of Broadband Cellular Network Technology

APPENDIX 4: METHODOLOGY OF THE RADAR GRAPHS

The purpose of the analysis presented below is to measure the resilience and development space of infrastructure sectors in the four main scenarios after the Covid-19 crisis.

Based on our framework of the analysis of the crisis, the four scenarios are characterized in light of megatrends pertaining to the threefold transition. For each category, the five most impactful megatrends for infrastructure sectors have been selected.

Each megatrend has been attributed a mark reflecting its relevance in the different scenarios, from -1 to 1: -1 when the megatrend declines; 0 when the megatrend remains unchanged; 1 when the megatrend grows.

Each megatrend has then been given a mark reflecting its impact on infrastructure sectors, from -2 to 2: -2 when the mega-trend has a strong negative impact in the considered infrastructure sector (compared to the status quo); -1 when the megatrend has a moderate negative impact; 0 when the mega-trend has a negligible impact; 1 when the megatrend has a moderately positive impact; 2 when the megatrend has a strong positive impact.

This methodology results in a resilience score, which reflects the least favorable scenario, and a development potential score, which reflects the most favorable scenario.

FACTORS	MEGATRENDS
ECONOMIC AND POLITICAL FACTORS	Deepening of globalization (opening-up of new markets favorable perspectives in emerging countries)
	Increasing end-consumer demand for services based on infrastructure
	Increasing public fundings for infrastructure (depending on the state of public finances and political priorities)
	Better management of raw materials (price, flows)
	Regulation favoring innovative and responsible players
ENVIRONMENTAL FACTORS	Better management of climate risks (impacts on operational risks and demand)
	Premium to higher quality and environmentally compliant assets
	Externalities included in value creation (thanks to tax carbon for instance)
	Development of abundant and affordable clean sources of energy (electricity, hydrogen, biogas...)
	Stronger resilience requirements (investments in critical infra, industrial sovereignty
SOCIETAL FACTORS	Rising restrained and frugality practices from end-consumers
	Digitalization of uses (remote working, education, etc.)
	Growing urbanization
	Promotion of the reduction of the territorial divide
	Emergence of local models (appeal for short channels, more local in initiatives)
TECHNOLOGICAL FACTORS	R&D and low-carbon innovation efforts to comply with the Paris Agreement
	Opportunities to develop data-driven models
	Development of 5G
	Ecosystem favorable to innovation (new actors competing with hyperscalers, data sharing)
	Institutions (labor market, education) promoting innovation

APPENDIX 5: MAIN BIBLIOGRAPHIC REFERENCES

Accenture Strategy (2015), #SMARTer2030: ICT Solutions for 21st Century Challenges

Atkinson, R., Castro, D., Ezell, S., Mcquinn A., New J. (2016), A policymaker's guide to digital infrastructure, Information Technology & Innovation Foundation

Bughin J., Woetzel J. (2019), Navigating a world of disruption, McKinsey & Company

Deloitte (2015), Industry 4.0: Challenges and solutions for the digital transformation and use exponential technologies

GSMA (2019), The Enablement Effect: the impact of mobile communication technologies on carbon emissions reductions

Isaac, H. (2018), « La donnée, une marchandise comme les autres ? », Annales des Mines, Enjeux Numériques, n°2, 20-24

Isaac, H. (2018), « La donnée numérique, bien public ou instrument de profit », Pouvoirs, n°164, n° spécial « La Datacratie », 75-86.

Komninos, N. and Kakderi, C. (2019). Smart Cities in the Post-Algorithmic Era: Integrating technologies, platforms and governance. Edward Elgar, Cities series

Komninos, N. (2020). Smart Cities and Connected Intelligence: Platforms, ecosystems and network effects. Routledge, Regions and Cities series

Laney, D. (2001), "3-D Data Management: Controlling Data Volume, Velocity and Variety," Meta Group

OECD (2017), Going Digital: Making the transformation work for growth and well-being

OECD (2017), Key Issues for digital transformation

OECD (2017), Technical note on estimates of infrastructure investment needs

Reinsel, D., Gantz, J., Rydning, J. (2018), The Digitalization of the World from Edge to Core, Seagate

Sarkar-Swaisgood, M. (2020), "COVID-19 reveals urgent need for infrastructure," UN ESCAP

Statista (2019), In-depth Industry 4.0 2019–Statista Digital Market Outlook

Woetzel, J., Garemo, N., Mischke, J., Hjerpe, M., Palter, R. (2016), Bridging Global Infrastructure Gaps, McKinsey Global Institute

World Economic Forum (2019), Transforming Infrastructure: Frameworks for Bringing the Fourth Industrial Revolution to Infrastructure

World Economic Forum (2019), "We're helping to close the global infrastructure investment gap by mobilizing the private sector"

World Economic Forum (2020), Unlocking Technology for the Global Gaols

World Economic Forum (2020), Global Risks Report 2020

/ Creation, design and production: Entrecom. / Conception & writing: Vauban Infrastructure Partners & Altermind / Photo credits: J. P. Mesguen / Vauban Infrastructure Partners. 2020 / ©DPA for Indigo.2020.