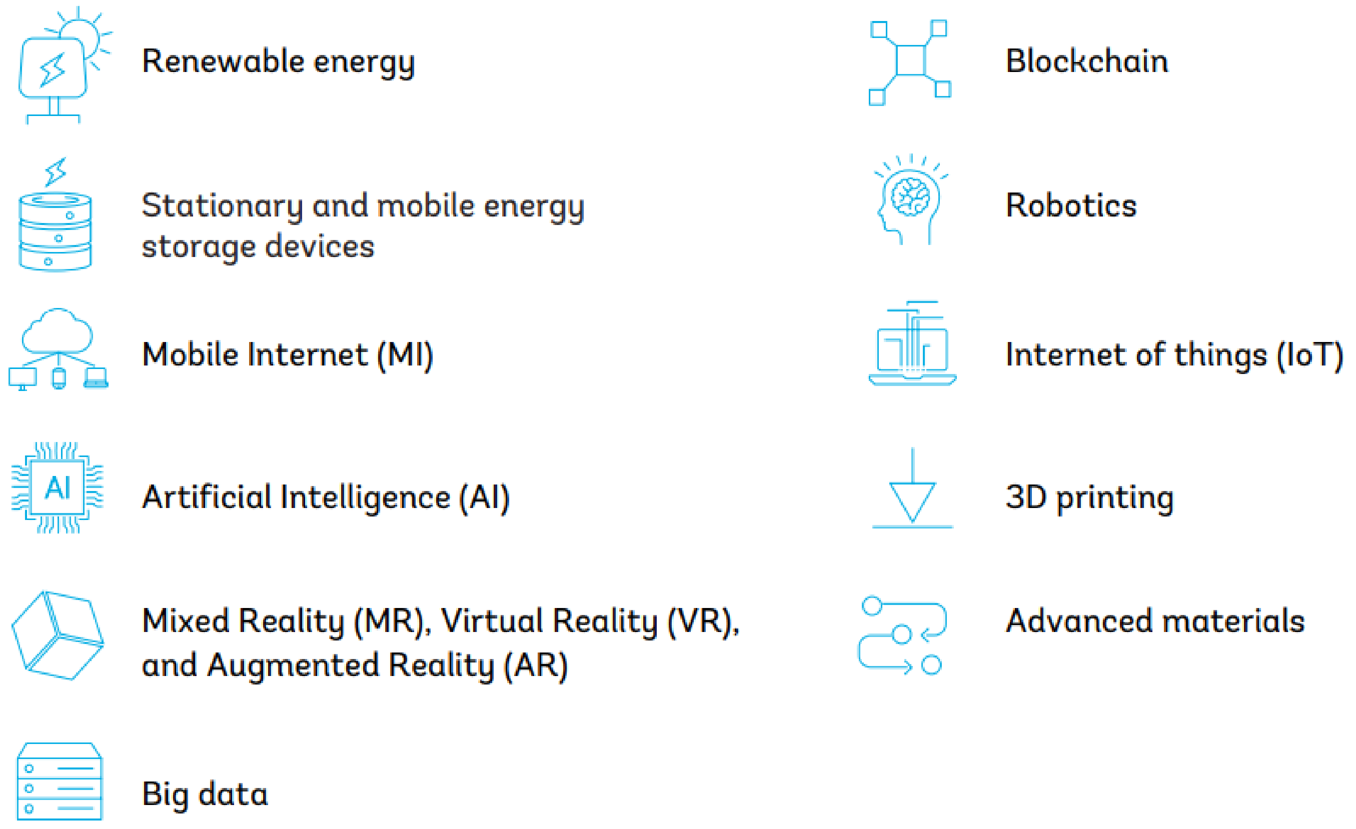
Examples of Disruptive Technologies and their Applications to Infrastructure

Full Description

The following is a non-exhaustive list of disruptive technologies and their impact on PPP infrastructure projects:



- **Renewable energy**
  - Generic description: Renewable energy refers to the generation of energy through renewable resources, such as solar, wind, water, geothermal or biomass. Advances in renewable energy technology, including solar PV panels and battery storage technology, together with a strong policy push in this direction, have made renewable energy technology a disruptive technology for conventional fossil fuel-based power generation.
  - Application to infrastructure: The power sector has seen significant transformation towards renewable energy and away from fossil fuels, with substantial cost decreases for solar and wind. Electrification with renewables is also underway in the transportation sector and already a viable option for rail and road transport. Renewables are also used to power smart cities. For more on renewables, see “Appendix B: Disruptive Technology in the Energy Sector.”

- **Stationary and mobile energy storage devices**
  - Generic description: Stationary and mobile energy storage refers to devices or systems that store energy for later use, including batteries. In recent years storage technology has advanced and prices have steadily fallen.

- Improvements in lithium-ion battery technology and materials, particularly improving sustainability, have resulted in increases in battery life, storage capacity, and production. Because of these innovations, the cost of lithium-ion battery storage has dropped almost US$1,000 per kWh in the last 10 years.[1] Green hydrogen has also become an important option for the storage of excess energy from renewable energy sources. Green hydrogen is hydrogen that is produced by electrolysis using electricity from renewable energy resources. The hydrogen can be stored and eventually re-electrified via fuel cells. The efficiency of this process today is as low as 30 percent to 40 percent, but it could increase if more efficient technologies are developed. Demand for hydrogen continues to grow due to much longer discharge duration and higher power capacity when compared to lithium-ion batteries (small-scale storage) or to pumped hydro and compressed air energy storage (large-scale storage).[2]
- Application to infrastructure: The transportation sector has spearheaded innovations in mobile energy storage systems, with the most used storage technology being lithium-ion batteries used to power electric vehicles. Lower-cost batteries and the continued optimization of battery technology have already prompted a high demand for electrical vehicles (EVs) and hybrid electrical vehicles (HEVs), which are also creating demand for new charging infrastructure that needs to be integrated into transportation networks. Other innovative infrastructure solutions, such as trains that run on roads and rails, also rely on battery technology for electrification. In the Netherlands the first passenger train powered by a hydrogen fuel cell, which produces electrical power for traction, was tested in 2020.[3] In the energy sector, lithium-ion batteries have become viable for in-home, behind-the-meter, and other localized energy storage, but most notably, have become important for stationary utility-scale renewable energy storage systems. Mini grids that use hydrogen as a complement to batteries are currently being tested.[4] For the energy sector this means that renewable energy sources, such as wind and solar that are weather dependent, can now be made available any time. In addition, the deployment of innovative stationary utility-scale, front-of-the-meter energy storage systems is on the rise, adding flexibility and reliability to electrical grids.

- **Mobile internet (MI)**
  - Generic description: The term “mobile internet” refers to the ability of mobile devices, such as tablets and smartphones, to connect to the internet. Mobile devices are becoming increasingly inexpensive, powerful and capable, while high-speed wireless networks advance rapidly. One recent technological advancement is the development of 5G, the fifth generation mobile network. With high bandwidth and real-time data transfer capabilities, 5G will dramatically enhance remote use applications.
  - Application to infrastructure: Parallel with the development of AI, machine learning, the IoT, and blockchain (see below), innovations in fiber optics and 5G technology have greatly increased download and upload speeds, and have enhanced reliability, capacity, and accessibility. High bandwidth and low latency from 5G will improve data capture and data access across project delivery processes. Sharing large amounts of data, including visual data, in real time will enhance transparency, informed decision-making, and data analysis.[5] It also will make building information modeling (BIM) technology possible, allowing developers to create data-based, digital 3D models of projects so that architects, engineers, and contractors can simultaneously collaborate. In the transport sector, 5G will facilitate vehicle-to-vehicle communication and vehicle-to-traffic- controller communication going forward. Smart cities are based on high-speed wireless networks together with IoT and AI solutions to manage and govern municipal water and waste management, electricity generation, and street lighting.

- **Artificial intelligence (AI)**
  - Generic description: AI refers to computer science that enables machines to function in ways usually associated with the human brain so that they can learn, process data, predict, problem-solve, and make decisions. According to the American scientist Marvin Lee Minsky, the father

of AI, it is "an application capable of processing tasks that are currently performed more satisfactorily by human beings insofar as they involve high-level mental processes such as perceptual learning, memory organization and critical thinking."[6] Machine learning (ML) is a subcategory of AI that allows a machine to learn on its own through experience and without human intervention.

  - Application to infrastructure: ML is also used in many autonomous and semi-autonomous devices, like drones, autonomous vehicles and artificially intelligent robots. The sensors on these devices relay real-time data, and ML enables the device to make a decision based on that data. For example, when an autonomous vehicle approaches a pedestrian, the sensors detect and relay the data, ML processes the information and makes a decision, and then the control system performs the decided action, i.e., to stop or swerve the vehicle.
  - Pilotless drones can be used to collect visual data, e.g., for urban air-traffic control to manage the flow of vehicles, or geo-spatial data for environmental and social assessments. Drones are also increasingly used in the freight and logistics industry. They can, for instance, be used to transport goods to or from isolated areas or to overcome the issue of last-mile delivery, which many logistics operators face in areas where road networks are either underdeveloped or poorly maintained. Future unmanned cargo planes will be large enough to carry hundreds of pounds of goods across hundreds of kilometers, with the potential to replace cargo airplanes and even shipping vessels in some scenarios.[7] As the technology progresses, road traffic may decline as fewer delivery trucks are needed. Another potential application of drones is for use as so-called air taxis.
  - Autonomous vehicles are likely to revolutionize passenger and freight transportation. A system of AVs, coordinating with each other and with a traffic controller algorithm, could increase lane capacity and dramatically reduce traffic time, congestion and energy use, thus making freight and passenger traffic on the road or urban transport systems more efficient. Due to their specific operating requirement, AVs will, however, need an entirely different transport infrastructure than conventional vehicles. Going forward, road, bridge and tunnel infrastructure may increasingly need to integrate sensing technology for AVs. EVs, on the other hand, will make some existing transport infrastructure—such as fueling stations—obsolete, as well as disrupt the market for conventional automobiles.
  - Finally, AI and ML can be used for preparing, designing, constructing and operating infrastructure assets. In the preparation stage, AI, together with big data and the mobile internet, can, for example, connect team members with real-time visual data, and will likely lead to faster and more informed decision-making. During construction, mini robots can help track work as it progresses. AI may be used to design the routing of electrical and plumbing systems, and develop safety systems at work sites in order to reduce accidents and safety hazards. In addition, AI is already used to pursue real-time interactions of machinery, workers, and objects on site, and alert supervisors of potential safety issues, productivity issues, and construction errors. It may thus lower the frequency of expensive errors, reduce the number of worksite injuries, and make building operations more productive.[8]

- **Mixed reality (MR), virtual reality (VR), and augmented reality (AR)**
  - Generic description: Virtual reality (VR) refers to a technology that replaces the reality with a simulated digital 3D environment, where the user is fully immersed in the virtual world. The user can look and move around the artificial environment and interact with its virtual features.[9] Augmented reality (AR) supplements the physical real-world environment through the addition of more data by audio, visual, or other means. AR can be defined as a live, direct or indirect view of a physical, real-world environment whose elements are augmented or overlaid by computer- generated sensory input such as sound, video, graphics or GPS data.[10] Whereas VR replaces the real-world environment, AR alters the user's perception of the real world environment. AR and VR are both part of a wider field of technology called mixed reality (MR). MR describes different technologies that can blend the physical world with the digital world.[11]

    - Application to infrastructure: MR technologies can be integrated in all stages of infrastructure planning, design and implementation.[12] They can, for instance, help to create immersive experiences that show how the new or upgraded infrastructure asset will look and how the design will interact with and impact the existing environment. MR thus can give insight into potential design flaws, risks, and other concerns during the infrastructure planning stage as well as during construction and operations.

- **Big data**
    - Generic description: The term “big data” describes the high volume of complex digital data requiring the use of advanced analytics for processing. This has meant discovering new orders of magnitude in the capture, retrieval, sharing, storage, analysis, and presentation of data. Thus, the term “big data” refers to the storing of huge amounts of information on a numerical basis.
    - Application to infrastructure: Big data and analytics will influence how we design infrastructure. Building information modeling (BIM) is already used for 3D modeling in the design and construction phase, so that architects, engineers, and contractors can simultaneously collaborate. This allows those who design infrastructure to provide real-time support to those building it. Advances in BIM technology will also increasingly provide insights into how a project will perform throughout its life cycle, allowing a view into a project’s future risk profile. Big data solutions also enable real-time collection of data from infrastructure asset operations, with a wide range of applications for the construction, management, financing, maintenance and operating of assets. Big data from weather, traffic, and community and business activity can be analyzed to determine optimal phasing of construction activities. Geolocation of equipment also allows logistics to be improved, spare parts to be made available when needed, and downtime to be avoided. During operation, big data from sensors built into structures can monitor performance. This means, for example, that energy conservation in buildings can be tracked to ensure it conforms to design goals. Traffic stress information and levels of flexing in bridges can be recorded to detect any out-of-bounds events. Data can also be fed back into BIM systems to schedule maintenance activities as required.[13]

- **Blockchain**
    - Generic description: Blockchain technology offers transparent and up-to-date verifiable transactions without the need for intermediaries. Blockchains are unique identifiable blocks (ledgers) of data organized in chronological transaction chains, with each new block referencing the previous block. They are decentralized and distributed on peer-to-peer networks. Generic blockchain technology was developed with the idea that the network would be permissionless and have open access for anyone to become a participant.
    - Application to infrastructure: Blockchain applications in infrastructure include everything from crowdfunding of power projects to enabling flexi-grid systems, interoperability applications for transportation mobility, and improving supply chain and logistics records.[14] The ports of Antwerp, Rotterdam, and Singapore have, for example, already employed blockchain technology programs to improve port efficiency. Blockchain technology can also be incorporated into the bidding and contracting process. A smart contact uses this technology to automatically execute an agreement when predefined conditions are met. Blockchain and the different mechanisms it enables thus have the power to increase transparency and predictability, reduce the risk for conflict and disputes, and make contract management more efficient.[15]

- **Robotics**
    - Generic description: Robotics refers to a technology designed for automating repetitive tasks. This technology is often based on the use of AI software or ML that makes “software robots” capable of imitating a human worker. The software robot connects to an application to manipulate data, perform calculations, communicate with other digital systems, or carry out various actions. For example, it may perform database inquiries, maintain records, or process

transactions.
    - Application to infrastructure: Existing robotic technologies deployed in construction, such as motion control, navigation, and computer vision, are expected to be augmented with complex physical and cognitive tasks in both the construction and operation of infrastructure assets. There are construction robots for bricklaying and masonry, and robots that lay an entire street at once, dramatically improving the speed and quality of construction work. Demolition robots may be slower than demolition crews, but they are safer and cheaper.

- **The internet of things (IoT)**
    - Generic description: The term IoT is used to refer to a system in which physical objects are connected to the internet and capable of creating, collecting, and exchanging data in real time in order to create value for its users. IoT systems often use embedded sensors and are controlled remotely. For example, thermostats, cars, lights, and refrigerators can all be connected to the IoT.
    - Application to infrastructure: IoT-based systems can help reduce traffic jams and pollution as well as water, light and energy usage, and are therefore used in many smart city concepts. The availability of data through IoT, and the speed at which the information is delivered, has improved efficiency, reduced costs, and increased transparency in the management of infrastructure. In Barcelona, for example, a citywide Wi-Fi and information network linked to sensors, software, and a data analytics platform has enabled the city to provide smart water technology, automated street lighting, remote-controlled irrigation for parks and fountains, "on-demand" waste pickups, digital bus routes and smart parking meters. These IoT-enabled urban services have dramatically reduced traffic jams and pollution, as well as water, light, and energy usage.[16]

- **3D printing**
    - Generic description: 3D printing, also known as additive manufacturing or digital fabrication, makes it possible to produce real objects from computer-aided design (CAD) files by stacking material in layers until the physical object is formed. A designer draws the 3D object using a CAD tool or 3D scanner. The 3D file obtained is processed by specific software that allows the 3D printer to read the design and to print the material layer by layer until the final part is obtained.
    - Application to infrastructure: Since it was developed in the 1980s, 3D printing has developed into a versatile technology that is used in more and more infrastructure sectors. With 3D printers now even able to build walls or process cement, 3D printing offers a broad range of applications for the construction of infrastructure assets, as well as for the on-site production of replacement parts for asset maintenance and repair. For example, when a component or structure needs to be duplicated in another location, use of 3D printing means that only the digital blueprint needs to be sent to the respective location, using 5G technology. The structure or component can then be assembled on site.[17] 3D printing therefore has the potential to reduce construction costs and delivery times significantly and will likely diminish wasted components. On the downside, the increased use of 3D technology will significantly reduce the market for transport and logistic services, and the need for supporting infrastructure (ports, etc.).[18]

- **Advanced materials**
    - Generic description: This category includes advances in the application of nanotechnology and emerging nanomaterials, which are produced by manipulating matter at the nanoscale (less than 100 nanometers). This level of manipulation allows for the development of materials that have greater reactivity, unusual electrical properties, and enormous strength.[19]
    - Application to infrastructure: Nanomaterials have a wide range of applications for infrastructure projects. Nanomaterials could, for example, be used to engineer construction materials for more durable, economic, and resilient road surfaces with improved geotechnical properties that reduce

costs and time for construction and maintenance.[20]

Footnote 1: BloombergNEF. 2022. Race to Net Zero: The Pressures of the Battery Boom in Five Charts. According to the BloombergNEF report, prices are edging ever closer to the US$100-per-kilowatt-hour mark at which EVs are expected to reach parity with internal combustion engine vehicles on an upfront cost basis. However, amid rising raw material and component costs, battery prices could increase for the first time since at least 2010 and climb to US$135 per kilowatt-hour in 2022, some 2 percent higher than a year earlier.

Footnote 2: Twinn, Ian. 2019. "Innovations in Transport." In Reinventing Business through Disruptive Technology. Washington, DC: International Finance Corporation.

Footnote 3: ENGIE. 2020. "ENGIE successfully refuels the world's first renewable hydrogen passenger train in test in the Netherlands." ENGIE (press release), March 13, 2020. (Last visited: September 13, 2022.)

Footnote 4: Silverstein, K. 2020. "Hydrogen May Be The Crucial 'Jigsaw' Piece For Green Microgrids." Forbes, July 12, 2020.

Footnote 5: KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020. (Last visited September 13, 2022.)

Footnote 6: Enkronos. 2020. "Artificial Intelligence: Definition, Advice, Comparisons, Testimonials…" Enkronos (blog), November 18, 2020. (Last visited September 13, 2022.)

Footnote 7: Global Infrastructure Hub. 2020. Unmanned Aerial Vehicles for Freight and Logistics.

Footnote 8: GlobeNewswire. 2019. "Artificial Intelligence (AI) in Construction Market to Reach USD 4.51 Billion By 2026." GlobeNewswire; KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020. (Last visited September 13, 2022.)

Footnote 9: Global Infrastructure Hub. 2020. Virtual and Augmented Reality for Planning and Design.

Footnote 10: GlobalData Energy. 2019. "Why augmented reality will increase safety and efficiency in utility sector." GlobalData Energy (comment), April 24, 2019. (Last visited September 13, 2022.)

Footnote 11: GIH (Global Infrastructure Hub). 2020. Virtual and Augmented Reality for Planning and Design.

Footnote 12: GIH (Global Infrastructure Hub). 2020. Virtual and Augmented Reality for Planning and Design.

Footnote 13: Burger, Rachel. 2019. "How the Construction Industry Is Using Big Data." LiveAbout, February 3, 2019; KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020.

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Footnote 15: Ernst & Young. Smart Contracts Using Blockchain Technology: a better way to deliver construction projects. IISD. 2022. Infrastructure Tokenization: Does blockchain have a role in the financing of infrastructure?

Footnote 16: Kranz, Maciej. 2018. "6 ways the Internet of Things is improving our lives." WEF, January 11, 2018. (Last visited September 13, 2022.)

Footnote 17: KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020. (Last visited September 13, 2022.)

Footnote 18: World Bank Group. 2020. Infratech Value Drivers.

Footnote 19: Texas A&M Transportation Institute. 2016. Disruptive Technologies and Transportation, Final Report.

Footnote 20: KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020. (Last visited September 13, 2022.)

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