Fight COVID-19 with a good indoor environment through Smart CFD simulations

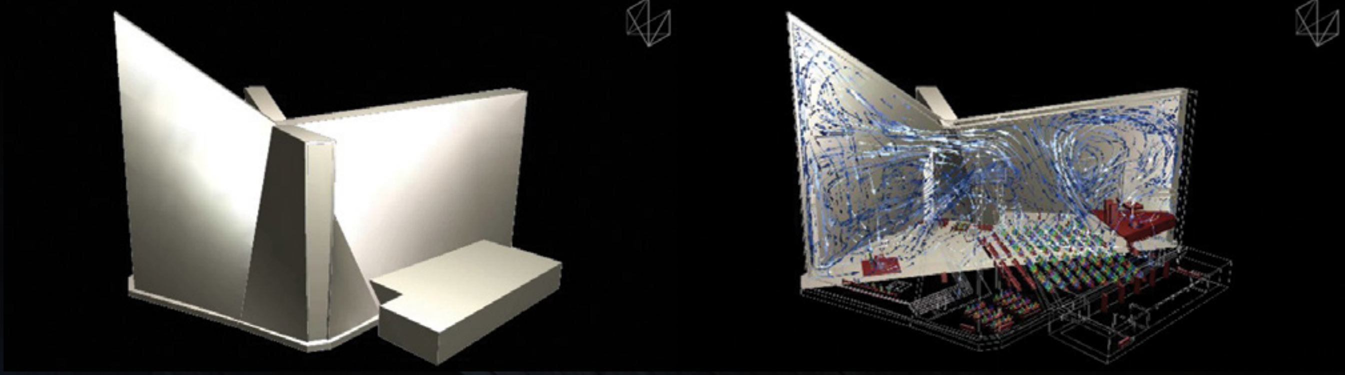
By Jonas Wirgart and ecoKaku Kyoto Technology Division

St. Mary's Cathedral in Tokyo plays a central role in the Catholic faith in Japan. The beautiful building pushes up to the heavens and has a complex shape of several roof sections that forms a cross when viewed from above. The cathedral is a large concrete structure where up to 800 people can gather. The question for the Archbishop of Tokyo was how to gather for Christmas mass safely during the COVID-19 pandemic. The primary source of person-to-person transmission for COVID-19 is airborne droplets carrying the virus generated by breathing, sneezing, coughing, etcetera [ref1]. Therefore, understanding how the airflow moves such droplets in the cathedral during mass with people inside is vital. Modern Computational Fluid Dynamics (CFD) tools can analyse this but require a detailed 3D model of the building, and as the building was constructed in 1964, no such data exists.

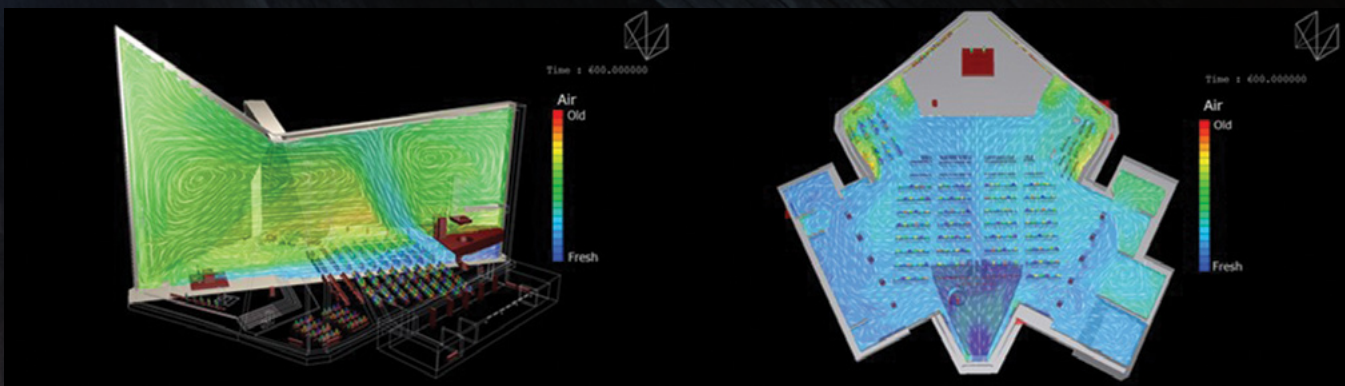
The Droplet Visualisation System by ecoKaku can demystify airborne droplets' movement and does not require detailed modelling in a CAD tool. This solution leverages the Leica 3D laser scanners and Cradle CFD from Hexagon to digitally transform the space enabling detailed analysis of how the droplets move within the built environment.

The model for the 3D scan of the cathedral was used in scSTREAM and the operating capacity of the building's air conditioning equipment was set up. All persons allowed in the building were included and were assumed to wear masks and seated according to the local recommendations. The heat transfer and fluid flow were simulated and in addition droplets exhaled by healthy and potentially infected persons, breathing or speaking was included and traced through the simulation.

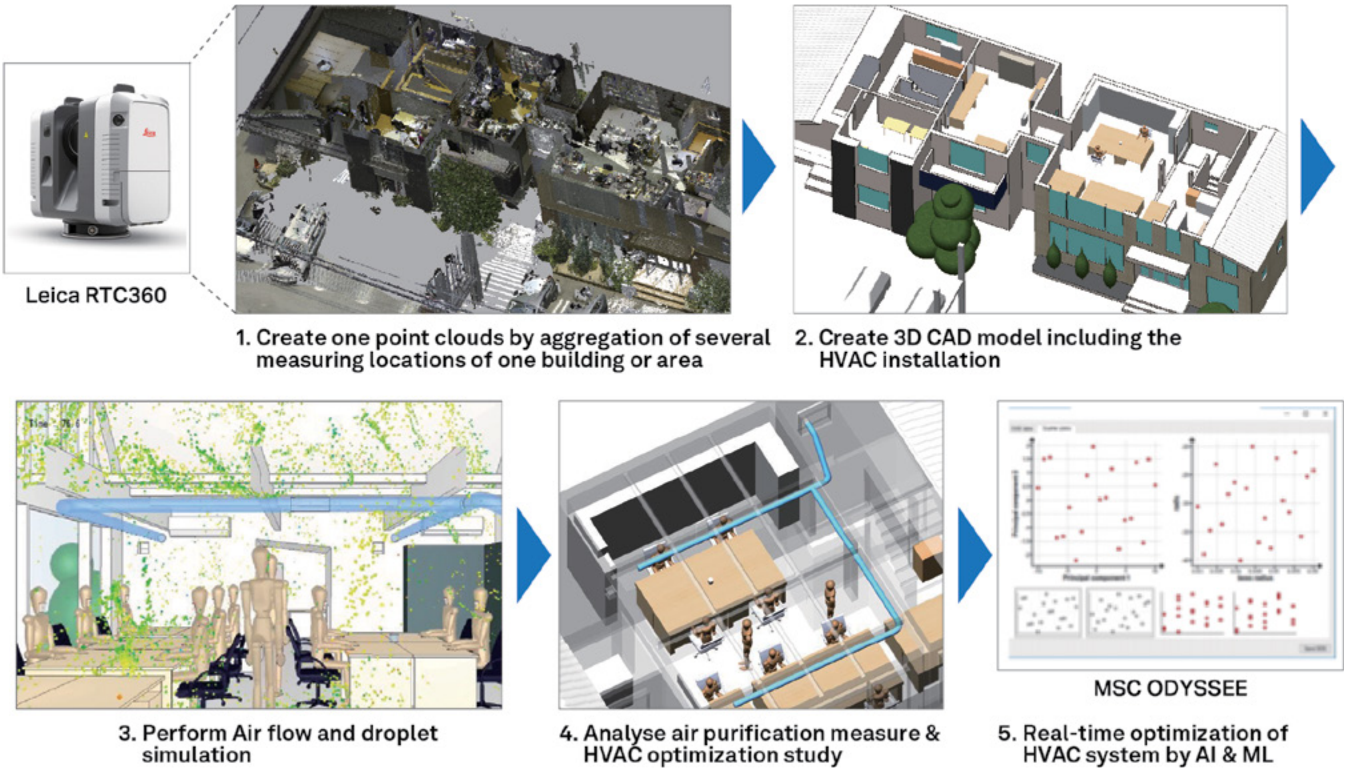
First, a steady-state of the airflow was analysed and visualised before deploying countermeasures. This



Appearance from the result file before countermeasures, display with flowing streamlines. Air cleanliness 10 minutes after the door is half-open.



Air circulation is visualised by how long it takes for air in a region to be replenished by fresh air. Red indicates a long time to replace the air in the space while blue areas fill quickly



The workflow of the 'Droplet Visualisation System.'

initial simulation showed that droplets that once rose by the natural convection vortex inside the building did not stay near the ceiling but were partially cooled by cold concrete and descended along the wall, landing on some of the seats along the walls. It turned out that some droplets kept drifting within the cathedral before falling to the ground. Closed spaces with poor ventilation are one of the 'Three Cs' to avoid COVID-19 outbreaks called out by WHO [ref5], Prime Minister's Office of Japan, and Japanese Ministry of Health, Labor and Welfare [ref6] so transient CFD simulations analysed the effectiveness of both air purifiers and improved air circulation by opening the 3 main doors in the cathedral. The simulation results showed that by opening the cathedral's doors, the air inside was replaced in 10 minutes. The simple solution by opening the door was chosen as simulation proved that it created a safe indoor environment.

On Christmas Day, the individual chairs were removed, and only parts of the church benches were used, signs put up so that people would not sit on the benches by the wall, and only one side of the three double doors was opened. A droplet simulation was projected on the cathedral walls, and elderly and people with underlying illnesses were guided to move to the central part of the cathedral to minimise their risk of exposure where droplets had difficulties reaching, and a mass was held.

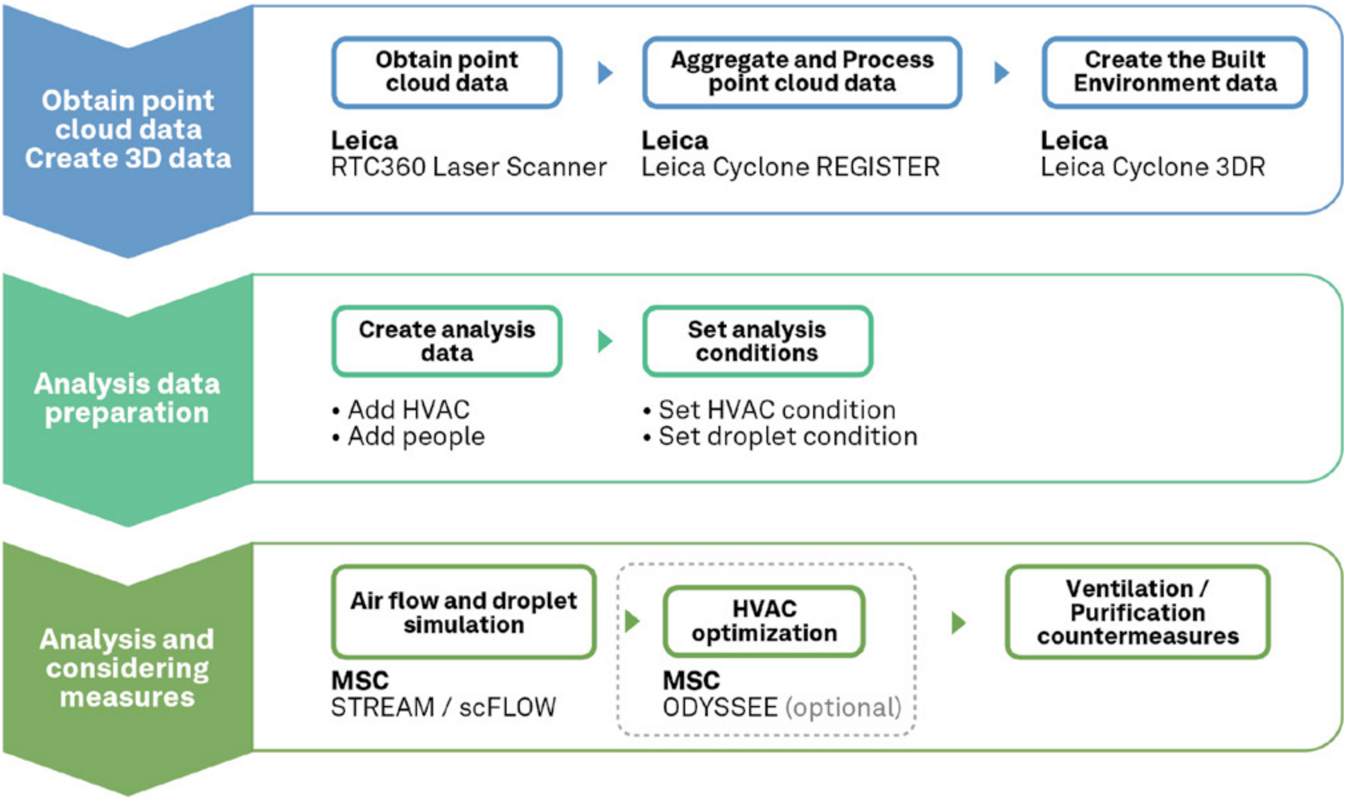
Developed 'Droplet Visualisation System' for simulation

The simulation conducted for St. Mary's Cathedral in Tokyo was based on the 'Droplet Visualisation System' developed by ecoKaku Kyoto Technology Division in the cooperation of Hexagon Leica Geosystems and Hexagon MSC Software. It is a consistent and time-effective process of analysing the spread of droplets that may contain pathogens.

This system leverages point cloud data of multiple locations to build a 3D model of the object with the 3D laser scanner equipped with an Inertial Measurement Unit (IMU), allowing the scanner to track its new position when moved; multiple data are combined to create point cloud data of the entire building. Based on the entire building's point cloud data, a 3D CAD model with air conditioning equipment is created, and CFD simulations is performed of airflow and droplet movements. With the simulation results, one visualises the droplet movement inside the building and identifies pathogen spread issues in the indoor space from the simulation results.

Development background-Verify the new coronavirus in virtual space and implement infection prevention measures

The primary infection mode is airborne droplets (aerosol infection) exhaled by infected persons for COVID-19 [ref1]. In order to prevent outbreak clusters, it is necessary to visualise how the pathogen spreads indoors to implement countermeasures such as optimised air conditioning and ventilation. However, the process of creating and simulate these scenarios and exploring possible countermeasures



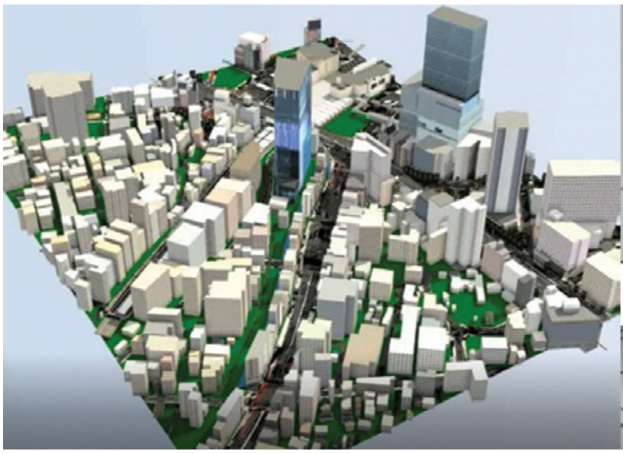
Digital Transformation of indoor environment workflow levering Hexagon technologies for real-time airflow analysis

takes considerable time. ecoKaku has, with Leica's point cloud acquisition-, Hexagon Cradle CFD-, and CADLM ODYSSEE technologies, converted the analysis from actual measurement data into a Reduced Order Model, ROM, enabling real-time 'what if' analysis while maintaining accuracy. This allows them to digitally transform the space and create a digital twin for countermeasure optimisation as for St. Marys Cathedral in Tokyo.

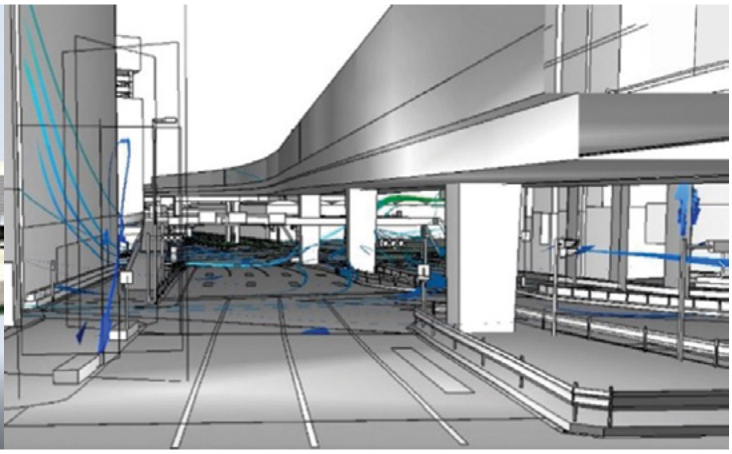
Environment and disasters prevention CFD analysis

The global climate is changing. This presents new challenges for civil engineers and city planners as areas previously safe now are prone to extreme weather suffering from floods, extreme winds by ever-larger typhoons, heavy rainstorms, and so on.

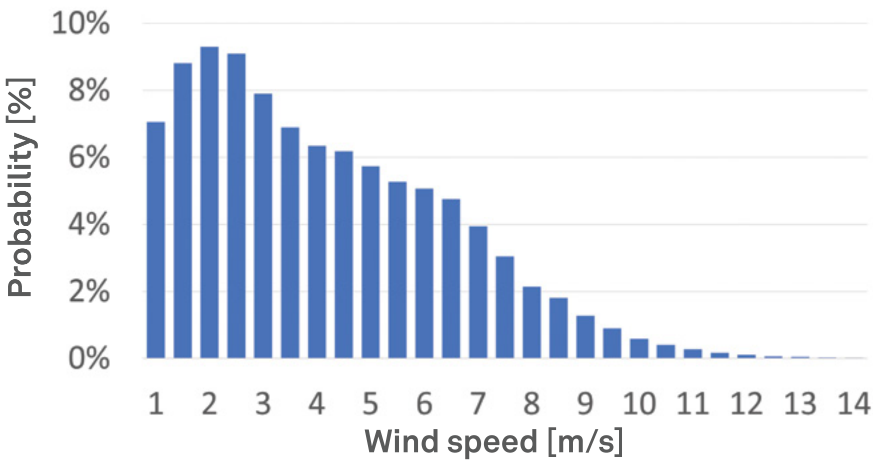
These new scenarios need investigations to prevent disasters and minimise the effects of extreme weather. ecoKaku have for years working with CFD analysis of the cityscape providing actionable reports for local government officials. Mr Nakata at ecoKaku explains:



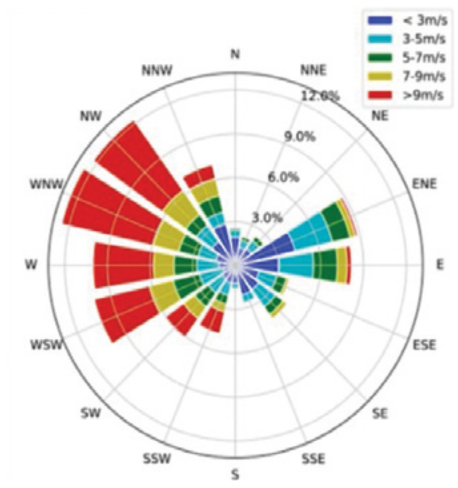
3D building GIS Data



Airflow under railway passage



Wind speed magnitude distribution

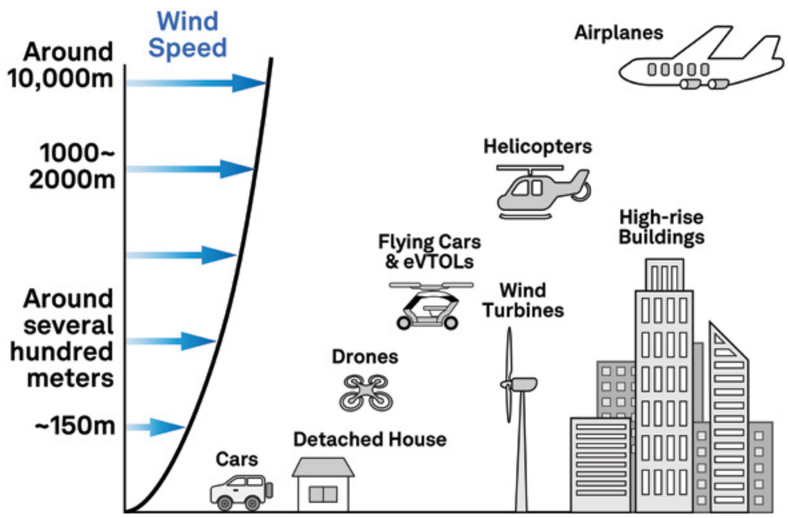


Wind direction distribution

"We use GPV[1] weather forecast or AMeDAS[2] meteorological observation data, which is the weather information provided by a supercomputer, to predict the wind speed distribution and wind direction distribution of a section of a city. These data are used in Hexagon scFLOW to make a detailed analysis of wind speeds considering the built environment. Further, we have built a wind prediction system in-house that allows us to quickly and efficiently deliver actionable results to our customers, which are involved in the decision making mitigating the effects of climate change."

With the GVP weather forecast or AMeDAS metrological observation data, CFD simulations give wind speed magnitude- and direction distribution for the detailed urban area, including elevation and buildings.

With this wind condition calculation data, it is possible to visualise any wind condition at any position and use it for grasping the situation at the time of a disaster. For example, one could; predict strong crosswinds channelled by large buildings, verifying the drone flight's safety, predicting the amount of power generated by the wind turbine (can be integrated into large buildings and skyscrapers), and assessing the safety and condition for eVTOL helicopters, etcetera.



Wind speeds at different altitudes

Furthermore, heavy rains can cause large damage due to flooding in residential areas if dams and floodwalls break. Depending on the local elevation, such areas are more prone to flooding than others, and policymakers usually use hazard maps to assess the situation. These hazard maps also affect the local property prices, so they are of great interest to the general public as well, and an example of the east side of Tokyo is shown that visualise the potentially catastrophic effects of a flood or tsunami can have on this metropolitan area hosting over 13.5 million people [ref3].

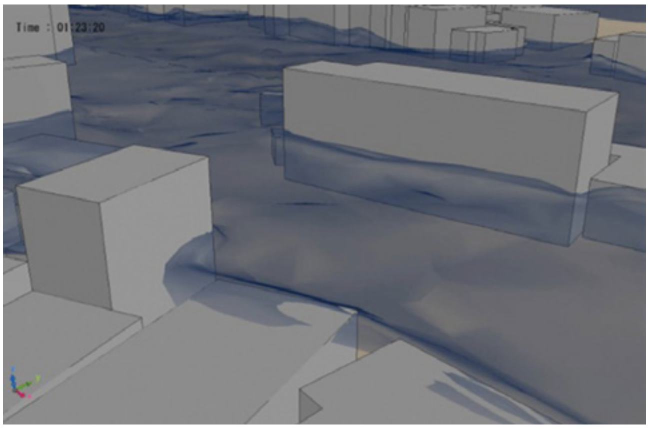
ecoKaku uses scFLOW that is a part of Hexagons Cradle CFD, to perform CFD analyses to analyse how flooding occurs and how the water spreads if a river bank breaks. These CFD simulations are based on satellite orthoimages, elevation and building data, predicting the building's inundation, and creating a detailed foundation for creating hazard maps.

"We at ecoKaku hope to help ensure the safety of residential areas in the event of a disaster."

About ecoKaku Kyoto Technology Division

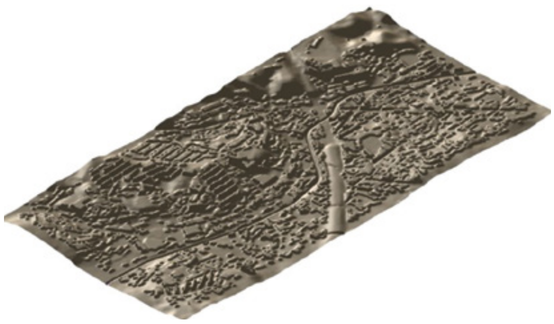
The ecoKaku Kyoto Technology Division is a research and development group established in 2019 in Kyoto, Japan, and is a part of ecoKaku Co., Ltd., your partner in renewable energy and solar power. ecoKaku Kyoto

Example Hazard Map from Koto City that is a part of the east side of Tokyo, the left side shows inundation levels where deep red is over 5m depth due to tsunami or heavy rain, and the right shows time it would take for the water after a flood to disappear, and red is over two weeks time [ref2].

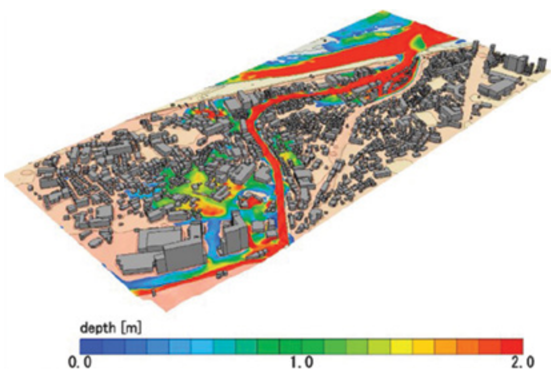


Flooding of a residential area

Satellite orthophoto



Wrapping of evaluation and building data



River flooding estimation

Technology Division strives to create new value in response to global environmental changes and social issues, with thermo-fluid analysis technology and mechanical design technology at the core, such as accelerating clean energy and ensuring safe flight of drones.

Notes

1 Grid Point Values, GPV, which are the result points from Japan Metrology Agencies wether forecast predictions.

2 Automated Meteorological Data Acquisition System, *AMeDAS*, used by Japan Metrology Agency is a metrological observation network for gathering regional weather data to verify forecast performance [ref4].

References

1. La Rosa G, Bonadonna L, Lucentini L, Kenmoe S, Suffredini E. Coronavirus in water environments: Occurrence, persistence and concentration methods - A scoping review. Water Research. 2020 2020/07/15/;179:115899.

Additional links:
https://www.ecdc.europa.eu/en/covid-19/latest-evidence/transmission
https://www.ecdc.europa.eu/sites/default/files/documents/covid-19-references-transmission-19-08-2020.pdf

2. Koto City in Tokyo 2018, <add Japanese title here> (in Japanese) , Koto City in Tokyo, viewed 11 March 2021, https://www.city.koto.lg.jp/057101/bosai/bosai-top/topics/documents/haza-do.pdf

Additional link:
https://www.city.koto.lg.jp/

3. Tokyo's History, Geography, and Population
Tokyo Metropolitan Government 2021, 「東京都の人口（推計）」の概要（令和3年1月1日現在）(in Japanese), Tokyo Metropolitan Government, viewed 11 March 2021, https://www.metro.tokyo.lg.jp/tosei/hodohappyo/press/2021/01/28/01.html

Additional link:
https://www.metro.tokyo.lg.jp/ENGLISH/ABOUT/HISTORY/history03.htm

4. Japan Metrological Agency, AMeDAS, Japan Metrological Agency, viewed 11 March 2021, https://www.jma.go.jp/jma/en/Activities/amedas/amedas.html

5. World Health Organization, COVID-19 - Avoid the Three Cs, World Health Organization, viewed 11 March 2021, https://www.who.int/brunei/news/infographics---english

6. Prime Minister's Office of Japan and Ministry of Health, Labor, and Welfare, Avoid the "Three Cs"!, Ministry of Heath, Labor, and Welfare, viewed 11 March 2021, https://www.mhlw.go.jp/content/3CS.pdf

Additional link:
https://www.mhlw.go.jp/content/000645566.pdf