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# Cities of the future

A look at urban challenges and technology applications for societal needs

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# Acknowledgments

This project-based learning is a very small project and it doesn't get close to the complexity and size of a masters' "thesis" or "mémoire", however, despite its simplicity and size, I want to acknowledge the support and help from my family, friends, and teachers.

A special thanks to Mr. Arnold Vialfont, Doctor in Economic Sciences, who accepted to be my tutor and helped me with the development of this project. I also would like to thank Mrs. Amélie Guillin, Doctor in Economic Sciences, for the support and help. Besides the simplicity of the project, it wouldn't be obvious to build it without access to the resources provided by the open-source community. I would like to thank Streamlit and Tensorflow for the amazing software you develop and provide to the machine learning community.

# Abstract

"*The 19th century was a century of empires, the 20th century, a century of nation states. The 21st century will be a century of cities*", said Wellington Web, former Mayor of Denver, Colorado. According to some estimations, 4.29 billion people are currently living in urban areas, this represents 55% of the world's population in 2020[1]. Considering the previous quote and data, it's natural to recognize the complexity and scale cities have and are expected to have in the next decades. However, such complexity and uncontrolled expansion are leading to a lot of urban challenges, putting the life of millions in danger and the next generation in peril.

This report analyzes how technology and data can help city managers, economists, engineers, scientists, and city dwellers to tackle some of the contemporary urban challenges, with the purpose of building more intelligent, flexible, and sustainable cities (i.e. smart cities).

The use of Machine Learning is certainly one of the most promising technologies for smart cities, with a wide range of applications, machine learning models can help cities to be more efficient in almost every ecosystem, from optimizing energy use to reduce waste of city space and traffic congestion with autonomous vehicles.

At the end of this report, I share with the reader a prototype project[2] that I built, with the intent of demonstrating how we, citizens, can collaborate and contribute to the development of smart city technologies for a prosperous future.

[1] Two-thirds of global population will live in cities by 2050, UN says
[2] HEPS - Paris Mollo

# Part I

## Need for change & urban challenges

## Introduction

During the COVID-19 pandemic, people around the globe have had the opportunity to rethink their attitudes and review what society is doing to our planet. Personally, a subject caught my attention. Could it be that after this health crisis, we could develop cities better prepared for an epidemic? Smart, flexible and efficient cities.

The role cities have in this crisis shouldn't be underestimated, more than 4 billion people live in cities, and are responsible for generating almost two-thirds of the global GDP. Because the side effects of Covid-19 are not merely "health issues", they aggravate a city's entire system[3] (i.e. logistics, transportation, governance, inequality, security, etc), cities will need to be better prepared, not only because a pandemic can rise again, but also because those issues were already present before the health crisis.

Cities are very complex systems, maybe some of the most complex achievements humankind has developed over the centuries. That said, cities have dozens of layers of complex ecosystems (i.e. economy, management, health, environment, transportation, security, etc.), where each of them is exposed to weakness and big issues that are affecting people all over the world.

In the United States, the crime rate in cities (urban areas) is 4 times higher than in rural areas. Also in the U.S, cities with the highest incomes earn up to 16 times more than

[3] *COVID-19: How cities around the world are coping*

the poorest cities[4]. Residents of Los Angeles spend an average of 116 hours per year in traffic.

In 2013, air pollutant emission thresholds were continuously exceeded in all London districts[5], the same happened in Stuttgart, leading up to driving restrictions during the period.

Those are some of the problems cities are facing in the northern hemisphere, but it can be substantially more critical in other regions of the planet. To find solutions for these issues, it's necessary to understand them first. In the next section, we will analyze some of those challenges and their consequences in our lives.

# Transportation & Mobility

## Importance of transportation and current situation

The transportation and mobility system has a vital role in our society, expanding exponentially and empowering people to get almost anywhere. Transportation is an enabler, it enables societies to trade, communicate, and promote economic growth[6]. However, due to its fast and uncontrolled growth, transportation is generating negative impacts in various dimensions of our cities (i.e. environment, land footprint, infrastructure costs, wellbeing, etc).

The population density in almost every major city on the planet is rising fast, cities as they are today, won't be capable of welcoming the population that awaits them for the next decade or so. Cities will get denser, both in terms of population and infrastructure (more households, buildings, etc) that will directly impact the size and number of streets and parking spaces availables, there is a necessity for innovation and change in how

[4] City and metropolitan income inequality data reveal ups and downs through 2016
[5] Smart Cities: Introducing Digital Innovation to Cities: Oliver Gassmann, Jonas Böhm, Maximilian Palmié: 9781787696143
[6] Urban Transport Challenges

we manufacture and design mobility, otherwise our current solutions won't fit the cities of the future.

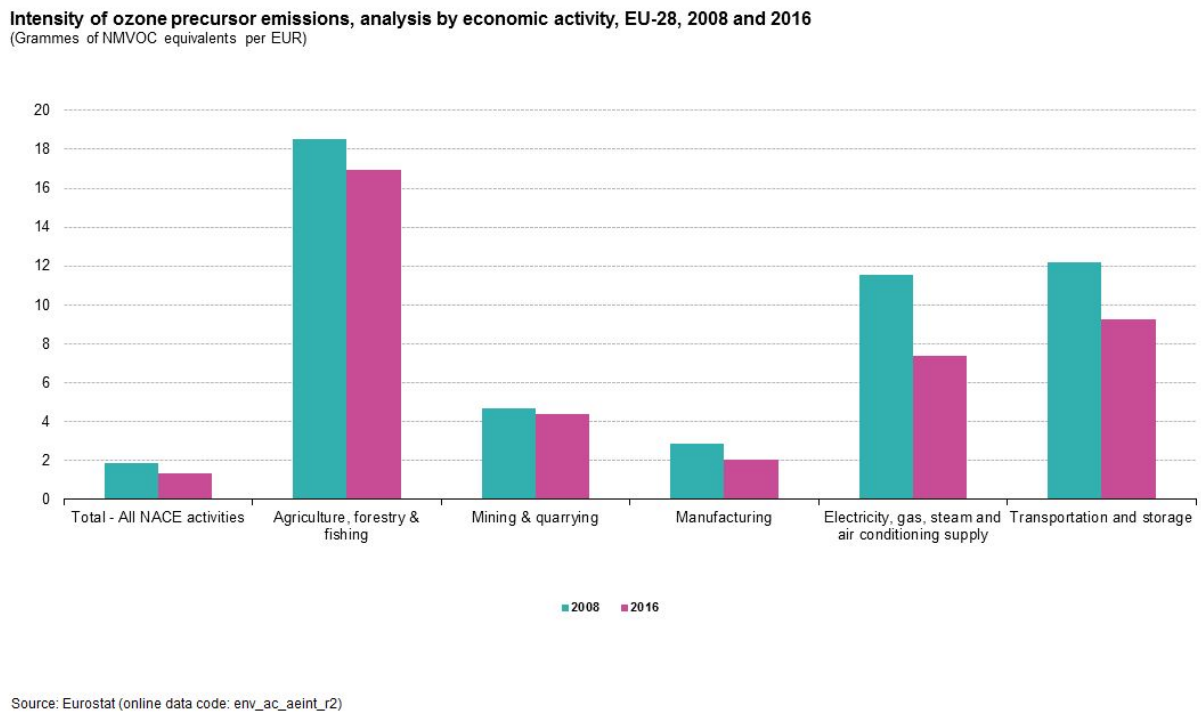
## Challenges

The fundamental problem of traffic congestion is based on a mathematical principle. During the last century cities were designed to grow vertically ; cities occupation capacity grows in a 3-dimensional framework (length, width and height - buildings), while the vehicles occupation capacity is 90% 2-dimensional (i.e. streets can increase in length and width). That said, it is clear that the number of people a city can inhabit increases faster than the number of its vehicles, leading to a almost inevitable saturation of streets and transportation systems.
Due to this saturation, people spend an increasing amount of time commuting between their home and work, which itself increases the number of accidents and decreases productivity.

The transport system as it is today requires a rather large volume of infrastructure. As the system becomes more saturated due to the incessant growth of cars, city managers need to relocate new areas of the city to try to desaturate and alleviate congestion, consequently, reducing and preventing social interactions, street activities, and open-air activities. A secondary effect of traffic congestion is that people tend to avoid walking and cycling when traffic is at its peak, city dwellers feel exposed to accidents and stress.

Cities' landscapes are changing fast, in such a way that the last century transportation infrastructure is no longer fitting it's city dwellers' mobility patterns. Inflexible and costly to maintain it, cities are spending fortunes to try to modernize their old infrastructures, in addition to the costs of circulation disruptions that frequent repair activities tend to have.

The lifecycle of an automobile is from production to destruction pollutant[7]. Automotive production leaves a tremendous land footprint to manufacture car components such as rubber, plastic, glass, etc.  Similarly, at the end of a car's life cycle, some car-parts such as plastic and toxic batteries will remain and impact the local environment.




Fuel production, i.e. petroleum extraction is already an energy-intensive process that is likely going to damage the local environment, even before reaching gas stations and car tanks. Obviously 90% of the environmental impact of cars comes from burning fuel,  and emitting greenhouse gases, that according to the majority of the scientific community is the main driver of global warming.

## Resources

Cities need energy and water resources to be viable and accessible to all its dwellers, but as cities are expanding in size, less space is available for water, energy,

[7] The environmental impacts of cars explained

food provisioning, and production required infrastructure, while demand for resources continuously grows.

### Water

There are still cities that don't have the required infrastructure to provide all citizens proper water access and sanitation. This lack of infrastructure and resources have serious consequences on the wellbeing of the population and can lead to health issues such as diarrhea, malaria and cholera outbreaks

In 2008 during a drought in Barcelona, the city had to import drinking water to meet the city dwellers' needs[8], since the local infrastructure including reservoirs and fountains were not enough. Over time, one of the global warming consequences is likely to lead to water shortages in some regions of the planet.

### Energy systems

Urban centers have a very dense and intense consumption of energy - electricity, around 70% of the global energy demand[9] is consumed in urban centers.

Energy consumption is increasing, largely due to economic growth. The vast majority of the electricity in cities comes from centralized generation facilities[10]. These facilities plants can affect the environment through pollutant gas emissions, waste generation, and high volumes of water discharge. Due to the nature of the centralized infrastructure, they are often exposed to overloads, inefficient distribution of energy, and are considered to be a single point of failure in some cases.

## Inequality & Poverty

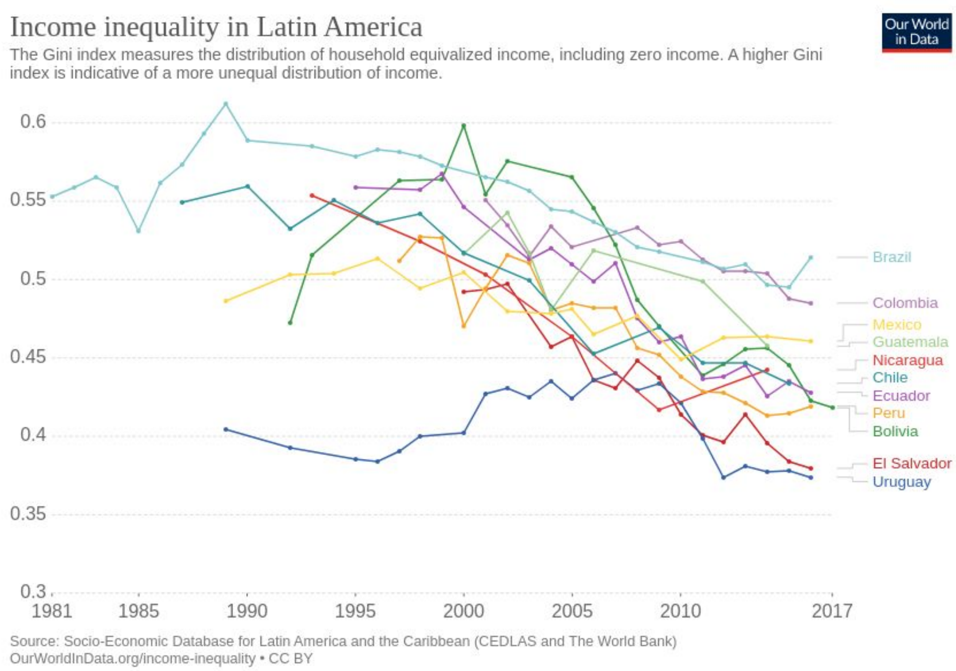
Cities are an agglomeration of people and activities that are supposed to collaborate towards the development of the community and common goals, however

[8] Thirsty Barcelona imports drinking water
[9] Expanding Cities Face New Energy Challenges
[10] Centralized Generation of Electricity and its Impacts on the Environment | US EPA

recently, cities are recognized by segmenting and dividing people, instead of connecting them.

Spatial inequality leads people in certain areas to be less likely to access jobs and quality education, the same works for healthcare and public transportation. It's also known that inequality is positively correlated to poverty, and therefore with crime and poor public health[11]. The disproportion of wealth distribution can also increase political instability and reduce poor people's political power.[12]

Take Sao Paulo as an example, the Brazilian megacity is known for its disproportionate distribution of wealth and education between neighborhoods, Jardim Paulista and Jardim Ângela are only 15 kilometers apart. Despite the proximity, citizens of Jardim Paulista have a life expectancy 24 years superior than their neighbours in Jardim Ângela region[13].




The last World Social Report (DESA) indicates that income inequality increased in most developed countries, even in fast-growing countries like China, inequality is

[11] The Two Cities: Inequality in Global Cities
[12] Spatial inequality and Development: An Overview of UNU-WIDER Project
[13] Living on the edge: São Paulo's inequality mapped

rising[14]. Inequalities start with an unfair concentration of opportunities, leading to a vicious cycle of inequality and larger gaps of education and health quality across generations

Inequality may be beneficial for the top 1% richest, which have had their overall fortunes increased during the last 20 years (share of global income), but in reality, inequality slows down global economic growth in the long run. The disproportional distribution of wealth, health, and education create poverty traps that will last for decades and slow global growth.

The rapid advance of technology and automation can jeopardize the work of thousands of people and this can only get worse for disadvantaged groups, without access to education and opportunities.

## Pollution

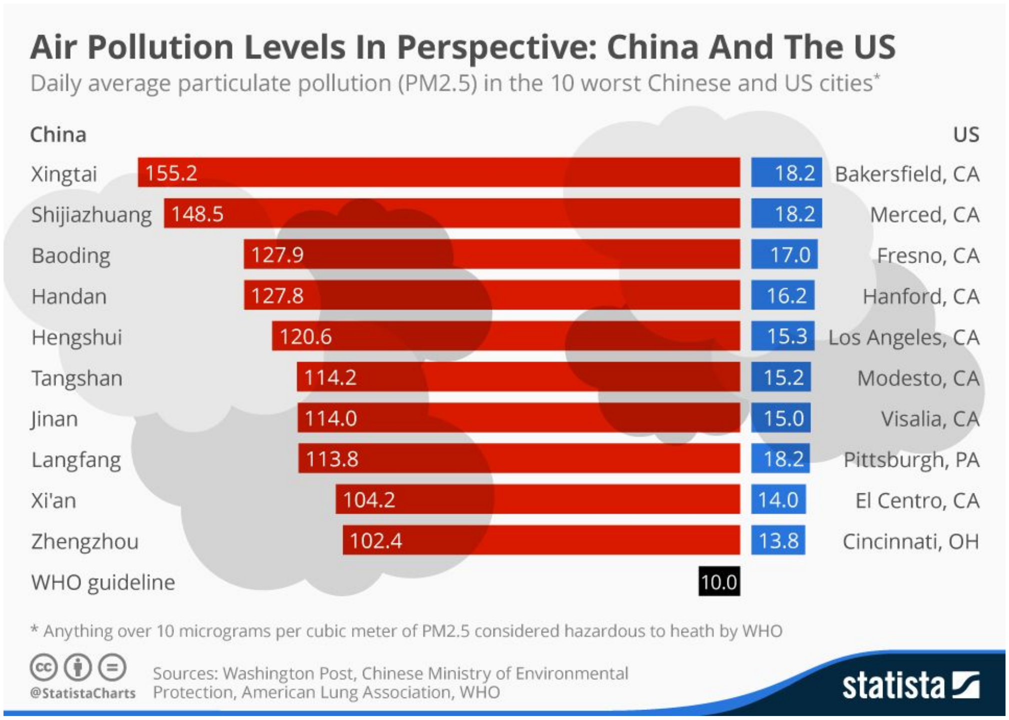
One of the most significant challenges that cities will need to face during the next years and decades is pollution, gases or particles composed by a set of specific chemicals (e.g. Carbon Monoxide, Nitrogen Oxides, Carbon Dioxide, etc) that can harm the health of humans, animals, and the environment[15]. In urban areas, domestic heating, agriculture, or industries play an important role in pollution emissions, but the biggest contributor is traffic (46%).[16]

Larger cities, in developing countries, tend to have more pollution than developed countries, but there are cities like Los Angeles, California that face major pollution problems despite being part of a developed country, in Europe, for example, 130 cities already exceeded the air quality standards.

Karachi, Pakistan; New Delhi, India; Beijing, China; Lima, Peru; and Cairo, Egypt are some of the most polluted cities in the planet according to the World Health Organization (WHO). In 2014, a report from the Shanghai Academy of social sciences

[14] Rising inequality affecting more than two-thirds of the globe, but it's not inevitable: new UN report
[15] The World Counts
[16] air pollution

said that Beijing, with the levels of pollution registered back then, was close to uninhabitable for humans[17].




Those statements are very serious, cities like Beijing or New Delhi are very dense cities (around 40 million people), the lives of millions of people are at risk, constantly exposed to harmful levels of pollution that could lead to a series of diseases later in their life.

Humans can be affected in the short term and severely affected by air pollution in the long term. Headaches, pneumonia, or bronchitis are some of the consequences for short term exposition while long term expositions can lead to death through heart diseases, lung cancer, or other types of respiratory diseases.

The environment can be also seriously affected, acid rain, water quality degradation, global warming (i.e. air and oceans rising temperatures), other examples such as reducing some animal's reproductivity can be also attributed to air pollution.

[17] [Air pollution: How three global cities tackle the problem]

## Security

Urbanization is transforming cities and shaping how people experience their social life at a fast disruptive pace, as a consequence, the way we protect and secure the wellbeing of the city dwellers has changed and became a very difficult task to master.

As cities grow in size and population (e.g. globalization), they become very complex systems, which have proven to facilitate the action of illegal activities, putting the wellbeing of the city and its dwellers in jeopardy. Organized crime, kidnapping or human trafficking are some of the many examples that have increased, as long cities increased in size and population[18]. Crime has also reached the virtual world affecting millions of people every day, either via fraud or cyberattacks.

Many cities have an uncontrolled and uncoordinated expansion, these expansions led to the development of peripheral fragmented smaller cities, due to its nature, they are often affected by the lack of security, education access, and good public transportation, creating another vicious cycle of inequality that will eventually increase crime rates on the region.

[18] The Evolution and Challenges of Security within Cities | UN Chronicle

# Part II

## Smart City

### What is a Smart City?

The elements introduced in the previous section are examples of the challenges cities face all over the world. To answer those challenges, cities need to reinvent themselves and innovate towards flexible, fully-connected, and intelligent systems.
Smart city is a term to designate cities that embrace the use of technology and data to build efficient and scalable services and networks, with the ultimate objective of benefiting and adapting to the needs of the city's inhabitants.

Cities as we know them today are mostly very inflexible systems. Due to the lack of transparency and embedded technology, the city managers know very little about the current state of the city's infrastructure, services, and dwellers. The impact of this approach is that city managers and politicians are reacting to the issues, often too late. A fallen bridge could be monitored through TITL[19] sensors so that accidents could be avoided, the outbreak of a pandemic could be identified sooner and controlled through DNA collection via sewers, as the MIT[20] has already demonstrated.
The fundamental characteristic of what we identify as a smart city is a complex system that is constantly collecting and processing data from its nodes, services, and citizens to adapt and respond to the needs on the fly.

According to the Institute of Electrical and Electronics Engineers (IEEE), the layers of a traditional smart city are based on 6 ecosystems: smart economy, smart living, smart environment, smart governance, smart people, and smart mobility.

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[19] https://www.jstor.org/stable/24092473?seq=1
[20] Stopping the Spread of Sickness with Sewage?

It's important to highlight that smart cities are not supposed to be autonomous or super-intelligent systems that will solve all the hurdles, while the city dwellers will be passive and not contribute to the development of the community. In the smart city context, citizens will be more responsible and active in decisions and developments of the city. One of the most important ideas is that there is a tendency that almost every consumer will turn to be a prosumer, (consumer that will also produce), this is the case for distributed solar energy networks, where citizens can sell each other the energy produced by their "domestic" solar panels.

To achieve this state of smart city, the book *Smart Cities and Digital Innovation* introduces the idea of a "digital shadow". A digital shadow is an additional layer on the city’s structure that will combine and connect the various implemented technologies running on the top of the city, from Internet of things to machine learning, the city will have a digital copy where any city planner, scientist, economist or engineer will be able to experience, analyze and visualize the city digital world as well as simulating scenarios

## Applications

Technology and data are fundamental components of intelligent ecosystems, in this section, we will explore three, among the several, applications of technology in the development of smart cities.

### Transportation & Mobility

Transportation is the core of every big city and its transition towards a sustainable and intelligent ecosystem will require structural changes in how we build and use our transportation systems. A smart transportation system is a system that produces less pollution, is safer, faster, and space-efficient.

- Computer Vision

Computer vision has several applications in the smart city context, one of the most promising is in the development of autonomous driving. Computer vision algorithms are being used by companies like Tesla to achieve superhuman levels of accuracy and environment perception. These algorithms are designed to detect and classify objects in numerous circumstances, they were built to prevent accidents and avoid collisions that humans are incapable of reacting on time.

Computer vision in autonomous cars is likely to increase safety, reduce accidents, and collisions. They are also capable of optimizing driving patterns and reducing time spent on traffic.

- Lithium-ion batteries & electric cars

Considering the environmental impact of the transportation system due to the emission of pollutants through fuel burning, the adoption of fully electric cars by car manufacturers and consumers is necessary if society wants to avoid a complete environmental collapse in the next decades.

Electric cars need to appeal to the average consumer, and it was only recently that companies like Tesla adopted lightweight and powerful lithium-ion batteries. These batteries have a high power-to-weight ratio, meaning that they are light and can provide a lot of energy, which increases the car electric range (e.g. travel further distances).

Fully electric cars have zero tailpipe emissions, and in addition to that, most of the lithium-ion battery components are recyclable. This combination has the potential to considerably decrease global pollution and be less harmful to city dwellers.

Despite the qualities of the lithium-ion battery, researchers are looking for new options, including flow batteries, thermal batteries, and gravity-based systems, which can be even more beneficial for the environment and appealing to the consumer.

## Energy Management

As cities grow in size and population, energy and water management complexity increases exponentially. Smart energy and water usage require efficient allocation, universal distribution, and optimized usage.

- Blockchain

Immutable ledger protocols, such as the Blockchain protocol, provide greater efficiency, safety, and control over commodity data and transactions. According to Consensys, a market leader in blockchain solutions "*Applying blockchain technology to commodity trading would be cheaper and more efficient than existing proprietary systems".* Similarly, the immutability and security of technology can remove the slow adaptability of large scale proprietary systems, cutting costs.

- Microgrids

Nowadays, most cities adopt centralized energy plant infrastructures, these centralized structures are often exposed to overloads, most of the time is inefficient in the distribution of energy, and are considered to be a single point of failure in some cases. Microgrids, however, shift the central station power plants to distributed and local generations grids.

Microgrids have the advantage to have a lower cost of maintenance, provide cleaner energy, and improve the regional electric stability grid, besides the larger distribution across the city.

## Health

A city with willing and healthy citizens is a city that has a better chance of developing and promoting an egalitarian, fair, and innovative society. Technology and Bioinformatics can help smart cities develop safer and healthier environments for their citizens

- Wearable Technology

Wearable technology, such as smartwatches provides more data over long periods, helping health professionals to better understand the issues affecting the population's wellbeing. The watch is constantly monitoring the patient, hence, the data provided is accurate and refreshed often, this can prevent patients from diagnosing diseases or conditions too late without having to do a medical exam.

The Apple Watch has two incredible applications that already saved many lives. The Apple Watch has a heart monitor that provides important information for the user and it can notify him in case of dangerous and unhealthy heart rates. Similarly, the Apple watch has a fall detector, which calls the ambulance once it detects that the person felt and isn't moving.

- DNA Sequencing

In 2019 a new virus spread in China and in 2020 the entire world was affected, countries under quarantine and sanitary restrictions. On the day of this writing, on June 11, 2020, 413.000 people died from COVID-19 according to WHO. This pandemic was not necessarily a surprise, scientists and people in the field have warned multiple times that nations and cities should be better prepared. Unfortunately, we were not prepared as we should, but this tragedy will be a lesson for future generations, that cities need to be built to prevent, detect, and control disease outbreaks.

One of the most promising technologies for preventing pandemic outbreaks is considered to be DNA technology to sequence raw sewage. DNA sensors would be used to detect which germs (bacteria, viruses, fungi, and protozoa) are in sewage in a particular location. This technology allows city managers, scientists, and health agents to map the origin and spread of a specific germ, facilitating the intervention and hopefully control the spread of the disease.

## Smart Economy

Building technology and designing intelligent and sustainable cities improves the quality of life from the city dwellers, in addition, it benefits the global and local economy. The research and development of smart city "technologies" are expensive, and it can cost a lot for the government to maintain it and test it, nevertheless, in the long term and medium term, it can tremendously benefit the urban economic growth.

Automation allows industries to produce with less human engagement, therefore reducing employment costs, as well as human errors. In 2014, Barcelona saved over 75 million euros due to the implementation of IoT technology in the city's water and electricity management center[21]. Similarly, microgrids and machine learning optimization algorithms can reduce energy waste and therefore costs. The prosumer[22] initiative can also generate economic growth.

The use of sensors, computer vision, and street cameras protect citizens and the city from threats that could endanger their well-being. In this way, the risks are mitigated and the costs of using security patrols and rescue teams are reduced. Furthermore, increasing the quality of life of citizens through the use of healthcare technology can increase people's productivity and thus economic growth.

The application of advanced data analysis, due to the development of Big Data, makes it possible for the extraction of important and valuable information for the development and maintenance of a city, resulting in cost savings and better governance.

The 2018 whitepaper "Role of smart cities for economic development" by ABI Research, demonstrates that the development of smart cities can generate over $20 trillion in additional economic benefits over the next decade[23]. This is essentially the result of opening up free access of city real-time data to third-party developers, economists, startups, and researchers, via an open application interface (APIs). Due to the democratization and free access to data, there is a tendency towards the development and design of innovative services and job creation by third parties never seen before, hence, expanding the global economy.

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[21] 'Social, innovative and smart cities are happy and resilient': insights from the WHO EURO 2014 International Healthy Cities Conference

[22] Consumer vs Prosumer: What's the Difference? | Department of Energy

[23] ROLE OF SMART CITIES FOR ECONOMIC DEVELOPMENT

# Part III

## Fire hazard detection with Convolutional Neural Networks

## Project Introduction

The rise of smart cities will accelerate the development of new technologies and spark the next generations to build solutions for the challenges discussed in the previous section, that said, I decided to build a project prototype that could illustrate a possible use case of Machine Learning for security and safety in a smart city, particularly for fire hazard detection.

## What problem does this project tackle ?

The fundamental ingredient of security and safety improvement in cities is information. The more information, as accurate and fast as you can get it, the greater the chances to intervene, control, and avoid criminal, illegal activities, and hazardous situations in the city.

As cities expand fast, it turns out to be very difficult to collect enough information on time to control and supervise the entire city. The 21st century's solution for that is cameras and sensors disseminated over the city. However, cameras have limits, when their quantity increases it's almost impossible computer-wise to save all the footage recorded by each camera and humanly impossible to read and analyze this tremendous data collection in real-time. Sensors, on the other hand, can trigger a lot of false positives and have often a very limited range and motion. Although current CCTV and sensor systems are very valuable and are helping local authorities battle crime, violence and hazards, there is still a margin for improvement. Machine learning algorithms can optimize the surveillance system by preprocessing most of the footage and identify what's more likely to be pertinent for further analysis or intervention, significantly reducing the workload for the surveillance authorities.

## What I wanted to do

The initial concept of this project implied building a web application that could identify fire hazards on images and output a description of the situation portrayed in the image (e.g. environment classification, objects classification, pedestrian detection). An application of this project in a real-life scenario is explained in figure 4.1. The machine learning algorithm would be preprocessing all the footage from CCTV cameras, once the algorithm classifies with greater than 50% confidence probability a hazardous fire scenario, it writes a full description of the situation and it adverts the closest fire department or security authority.

This framework could substantially improve the efficiency of fire fighting in smart cities, it reduces the time to detect hazardous situations, hence it speeds up the fire department time to act. In theory, this architecture could work without human supervision or city dwellers' emergency calls, but this doesn't correspond to the current state of technology and security protocols. Soon, it's likely to have a significant transition where it would be pointless to have human supervision and this type of software would immediately communicate with the fire department.

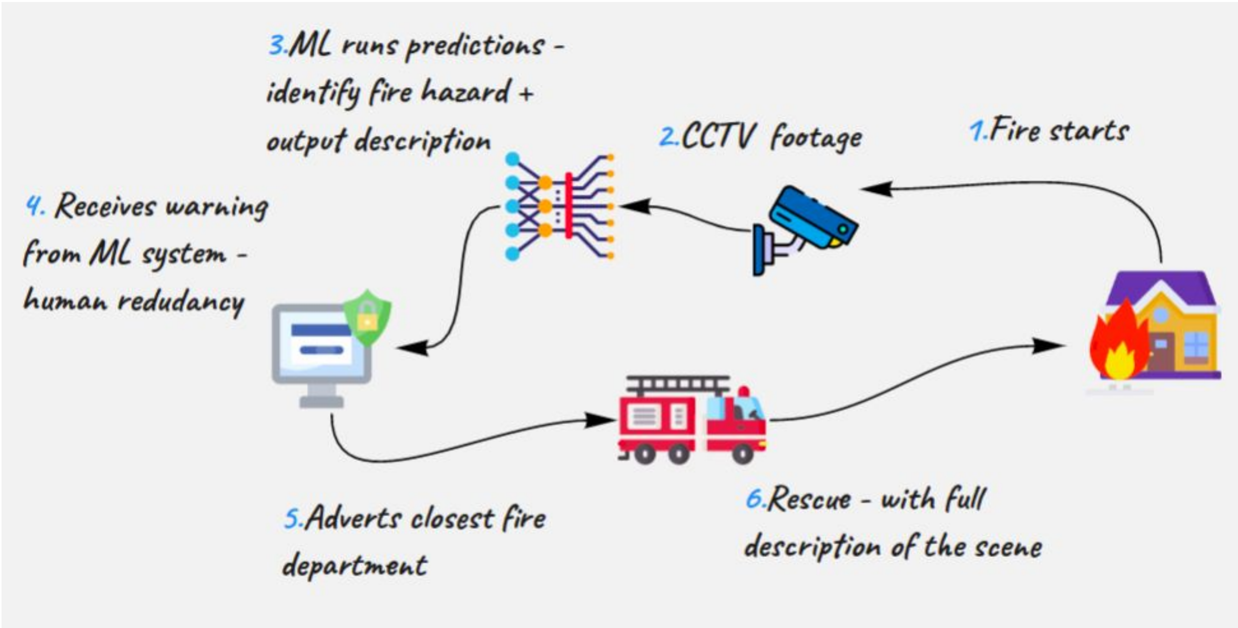



*Figure 2.1*

## What I did

At the current published version of the project (*Alpha v0.4.1*) the project is deployed on a Heroku server[24] where users can access and test the machine learning models precision. The *Alpha v0.4.1* app has two modes, "*demo*" and "*How it works*" mode, at demo mode the user can select a jpg or jpeg file of his choice and load it to the server, next, the app will display 4 models labels on the sidebar menu, where each will output a classification/prediction probability set.

***Note:*** *Alpha v0.4.1 has the following models: CIFAR10[25] object classification, Fire detection, Pedestrian Detection, and Scene classification.*

The app also provides an interactive display of each layer of the convolutional neural network output (i.e. feature maps), plus its filters (See section "*Convolutional Neural networks*") at app mode "*How it works*".

**Note:** *In the original version of the app (Github repo only, not available at Heroku) the user can further inspect the model's architecture, shown on app mode "evaluation", in*

[24] Machine Learning App
[25] CIFAR-10 and CIFAR-100 datasets

*addition to that, the user can evaluate the models' performance on a set of images pre-loaded in the app.*

The app was initially built using TensorFlow v2.2.0, unfortunately, the package size of this version of TensorFlow is around 530MB, which exceeds the "slug size" limit of 500MB for deployment on the Heroku cloud platform, due to this limitation I decided to clone the repository (using Tensorflow v2.2.0) and rollback the cloned version to Tensorflow v2.0.0, which is around 83MB, consequently I could deploy this version to a Heroku server.

The model's performance varies according to each task, but overall they all reach over 75% accuracy on test sets. However, there is still a lot to be improved and this is far from production required accuracy levels. The datasets sizes were relatively small for some tasks and will need to be improved for the next versions of the project, either by collecting more data or by generating random changes on the train set to increase the model's generalization.

## How it works

The project can be parted into 2 components, Models Research & Development, and Web app development.

### Models R&D

To build a sustainable and scalable project, I followed the "step-by-step" organization recommendations proposed by Aurélien Géron on his latest book "*Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow*"[26] and *Jason Brownlee tutorials*[27].

[26] Hands-On Machine Learning with Scikit-Learn
[27] Machine Learning Mastery

Step number one consisted in defining my objectives and framing the problem my models would tackle (See Section "*What I wanted to do"*). Once I defined the model's tasks (e.g. fire detection), I started my search for available datasets. The Fire[28], Pedestrian[29] and Scene[30] datasets are public datasets available on Kaggle[31], while for the object detection I used the CIFAR10 dataset, directly available at Keras[32].

After finding which datasets I was going to use, I started my development. At Kaggle or Google Colab (for CIFAR10) I wrote a python script that would:

1. Load the data.
2. Preprocess the data (normalization or standardization).
3. Discover and visualize the dataset (shape and instances).
4. Create a machine learning model (Sequential, optimizer, compiler).
5. Train the model on the train set and validate it on a validation set.
6. Evaluate model (overfitting, underfitting, generalization, etc)
7. Fine-tune the model (hyperparameters)

This can be implemented simultaneously in multiple architectures, to evaluate which architecture works the best. Once I found the best performant model, I saved the trained model in the TensorFlow h5 format to be later used in the web app.

There is a lot of relevant information in the steps mentioned above, such as the different techniques used for normalization, the model's architecture and hyperparameters, optimization algorithms, techniques to reduce overfitting, data augmentation and more, unfortunately, this report will not cover all these topics, but the

28 FIRE Dataset
29 pedestrian no pedestrian
30 Intel Image Classification
31 Kaggle: Your Machine Learning and Data Science Community
32 Keras: the Python deep learning API

notebook-code will be adequately commented with a few explications of the techniques that I decided to use in each model.

### Web app

The priority of this project is the development of machine learning models, however, I believe that it's important to provide a friendly interface where people can understand how the technology works and test the code, and hopefully give feedback. That said, I decided to use Streamlit[33], which is the framework I used to build the web app. The web app allows users to interact with the machine learning models, their architectures, and layers.

After saving the trained machine learning models created in the R&D section, I load them on the web app and use it to run predictions from the user input (via Streamlit), once the models output their predictions, I display it on the interface for the user.

## Models

So far I've presented the overall structure of the project and its features. This segment, nevertheless, will focus on explaining how the machine learning models used in this project work.

***Note***: *This report doesn't intend to cover details on Machine Learning, we will only be covering the necessary information for this project.*

### A quick overview of Machine Learning

"*A computer program is said to learn from experience E concerning some task T and some performance measure P, if its performance on T, as measured by P, improves with experience E", said* Tom Mitchel in 1997.

[33] Streamlit — The fastest way to build custom ML tools

Tom Mitchel's statement describes the fundamental mechanisms of machine learning programs. In principle, a machine learning algorithm is a computer program that learns from data (e.g. identifying patterns in images), to complete a specific predefined task (e.g. fire detection).

The ultimate objective of the machine learning model is to find the algorithm parameters that will optimize the model's performance, so that the model can generalize adequately and perform well on new data.

There are many techniques inside the Machine Learning field, one of the most popular ones are Artificial Neural Networks (ANN) which are vaguely inspired by the human brain's biological neurons.

## Convolutional neural networks

Similarly to ANN, Convolutional Neural Networks emerged from the study of the human brain, except this time, the technique tries to simulate (vaguely) neural patterns located in the brain's visual cortex.

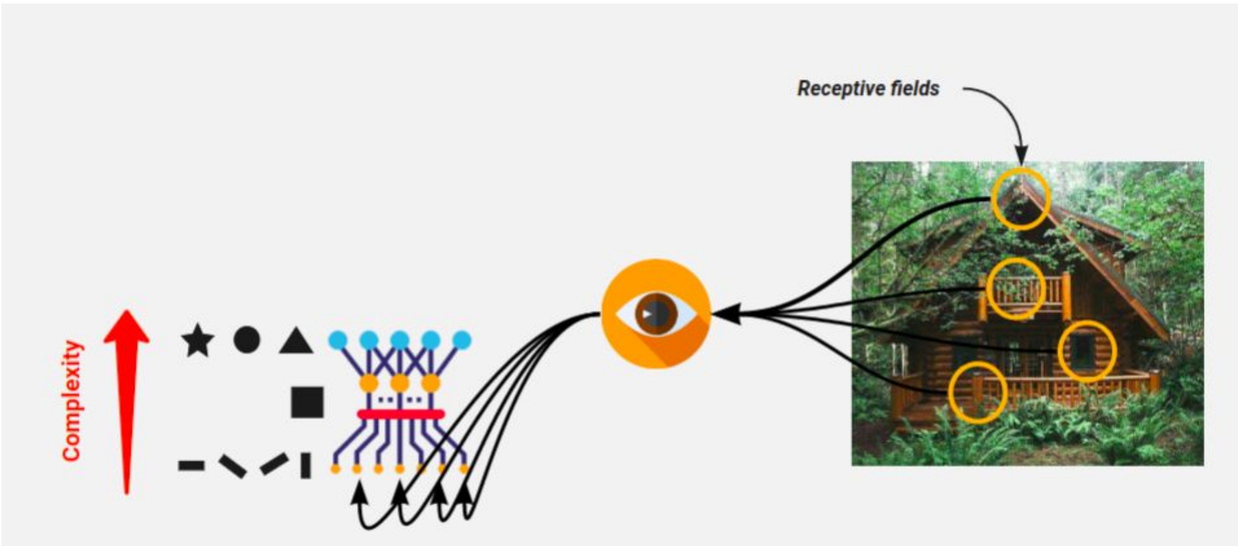
Convolutional neural networks are a category of deep learning algorithms, known by its performance on image recognition tasks. Due to the recent increase in computational power, available data, and machine learning techniques, CNN's achieved superhuman levels of accuracy in some image recognition tasks.

Despite being a type of deep learning algorithm, CNN differs structurally and functionally from "fully connected deep learning networks". Inspired by the groundbreaking studies of the visual cortex from David Hubel and Torsten Wiesel[34] CNN's layers aren't fully connected networks, following the mechanisms from "local receptive fields" found in visual cortex neurons, each layer of neurons will only react to visual stimuli located in a limited region of the "visual field".

Some neurons will only react to images of horizontal lines, while others will react for vertical or diagonal lines. Some neurons will react to complex shapes and will have

[34] Neurophysiologists Wiesel, Hubel receive Golden Goose Award for their contributions to our understanding of how brain processes visual information

larger receptive fields as well. Thanks to these discoveries, we observed that higher-level neurons are based on the outputs of neighboring lower-level neurons.




*Receptive Fields - figure 3.1 adaptation from : "Hands on Machine Learning - Aurélien Géron "*

In 1998, Yann LeCun introduced the famous "*LeNet-5"* CNN architecture, known by its use in banks for handwritten check numbers recognition. This famous architecture has some building blocks that were already used in traditional fully connected deep learning networks, such as Dense layers[35] or Sigmoid activation functions[36], however, it introduces two new building blocks: convolutional layers and pooling layers.

The principal constituent of a convolutional neural network is a convolutional layer. Convolutional layers are responsible for the application of "filters". Filters identify specific features through a "matrix" operation known as convolution. The result of the convolution will be a feature map (i.e.highlighted features of the input. See *figure 3.2*).

[35] Dense layer
[36] Activation Functions in Neural Networks

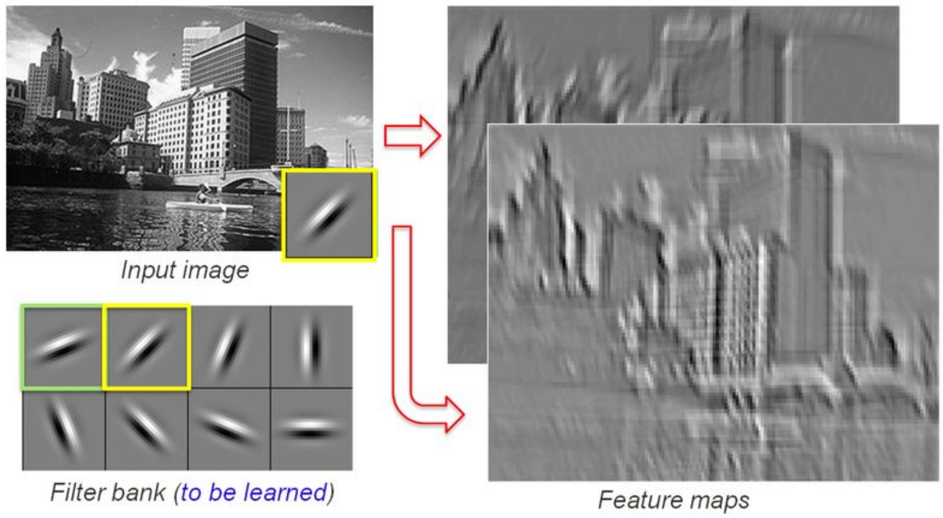
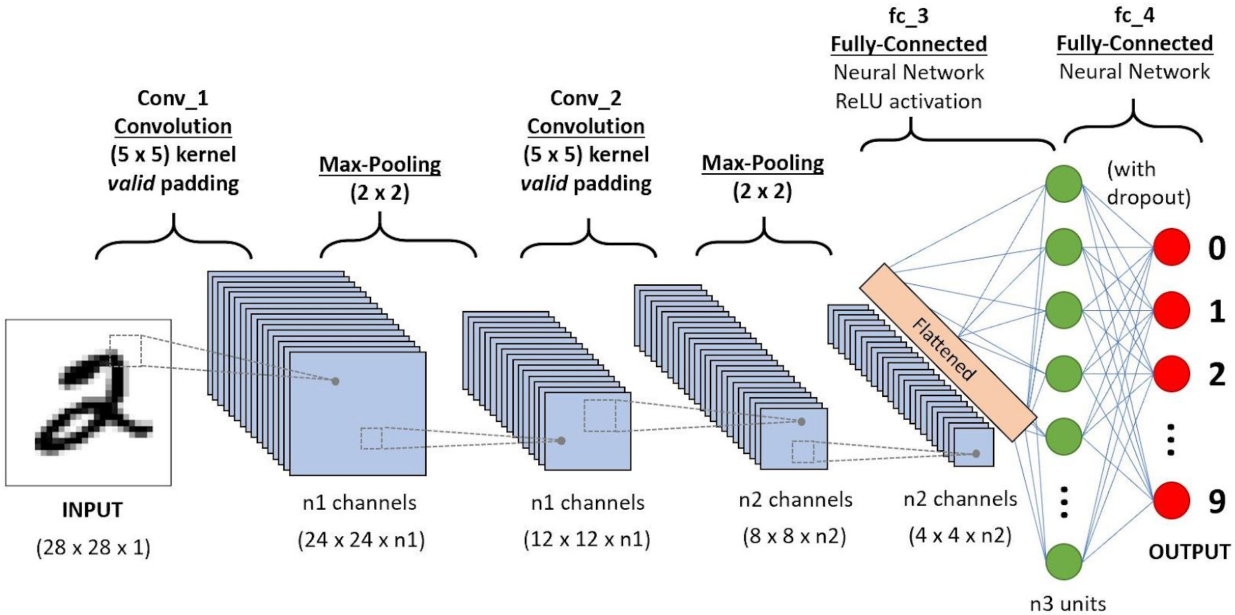



*Figure 3.2- **source**: unidentified*

Pooling layers are simpler to understand, their role is to reduce the CNN complexity, computational load, and overfitting through the reduction or shrinking of the input (i.e. an image).

The overall structure of a CNN can be represented as a sequence of convolutional layers, responsible for the identification of features (e.g. lines, circles, shapes, etc ) and pooling layers, responsible to reduce the computational load of the network. Deeper layers are likely to identify complex shapes, while the low-level layers will identify simpler shapes.

**Note**: *More details on how Convolutional layers work will be presented on the project web app (e.g. feature maps, filters).*




*CNN Architecture - **source:** [A Comprehensive Guide to Convolutional Neural Networks — the ELI5 way]*

## Work methodology

The project was created in around 4-5 weeks of development, each week had a specific topic and pre-establish goals that would change over time, according to the needs of the project. The figure 4.2 recaps the technology used for the development/organization of the project and the weekly tasks.

### Week 1

- Research the best suitable method for the development of image classifiers, lecture on researches, and articles made on that topic and analysis of similar projects made in the field.

### Week 2

- In-depth research on Convolutional Neural Networks. Try some CNN's snippets and notebooks on the topic to better understand how it works, step by step.

### Week 3

- Development of a small version of the project

### Week 4

- Research on potential improvements

### Week 5

- Scale and increase performance and project quality

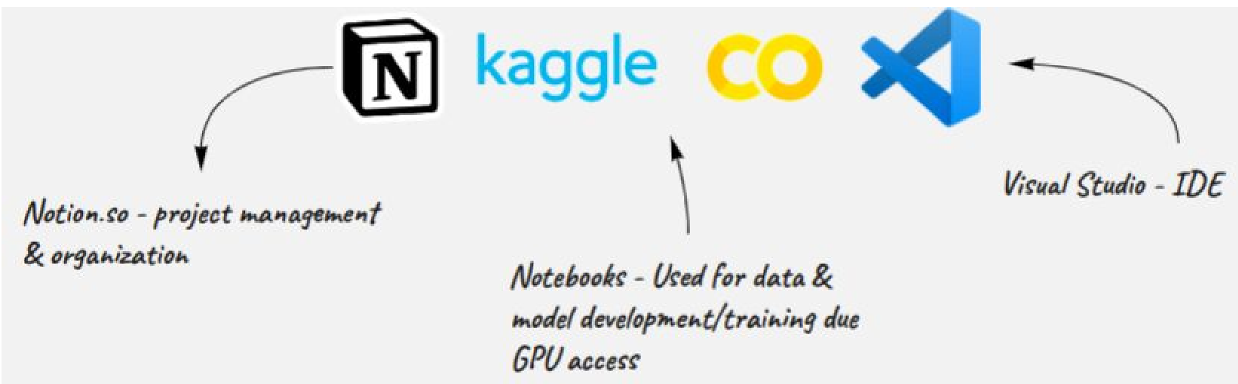



*Figure 4.2*

## Challenges & Improvements

Due to the nature of the data (i.e. images) and the size of the dataset, it was very unreasonable to train the models using a CPU, fortunately, Google Colab and Kaggle provide access to GPU, which made training very fast.

The fire and pedestrian datasets used at the version Alpha v0.4.1 are relatively small and need improvement. The fire model still predicts a lot of false positives, (e.g. images with a lot of yellowish pixels, or bright pixels) and the pedestrian model can't perform well on images with a lot of components, such as cars, buildings and multiple objects on the ground such as traffic signs.

Another valuable improvement in the fire model is to correctly classify hazardous fire and distinguish it from the intentional fire such as campfires, burning candles, etc. The current version of the project works only with images, a next step would be the implementation of video preprocessing and a potential online training feature, where users can give the feedback directly on the app and label more data for the model.

Other improvements for next versions would be:

- Prediction Speed
- Models Performance
- CIFAR100 implementation (increase the number of objects capable of classifying)
- API access

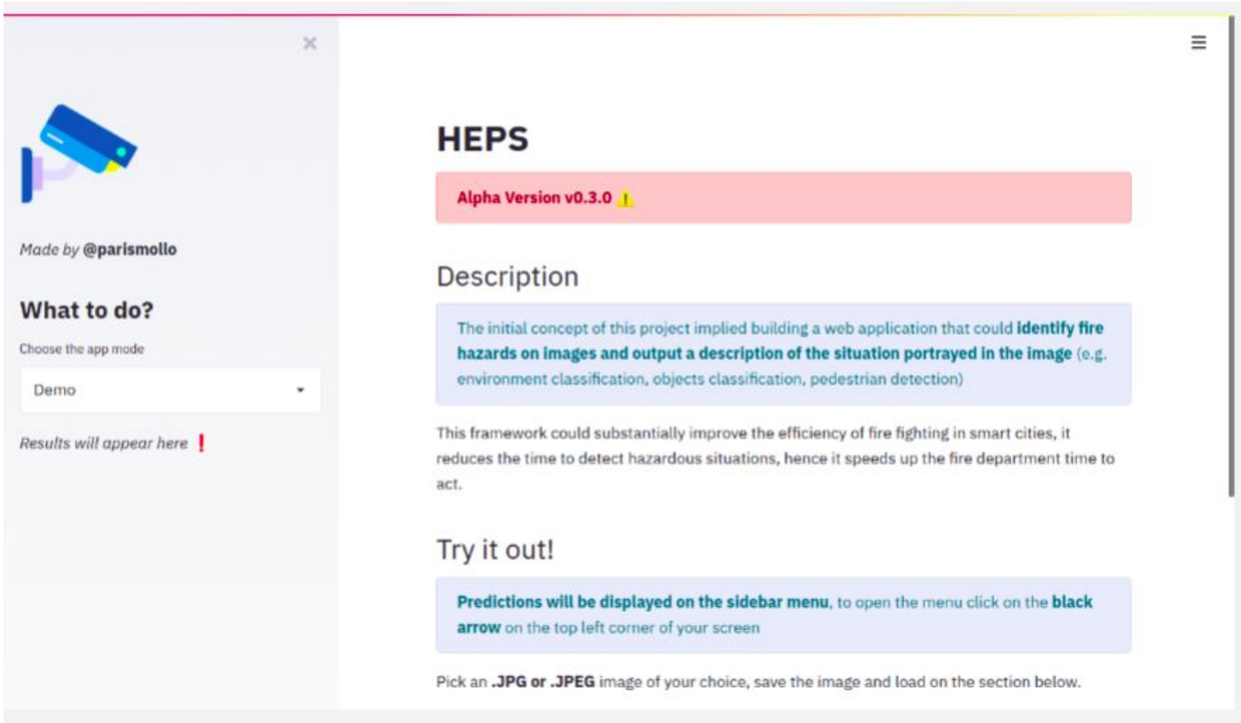
## Try the code

**Note**: *The application works both on the mobile and desktop browser, however, the tutorial screenshots are from the desktop version.*

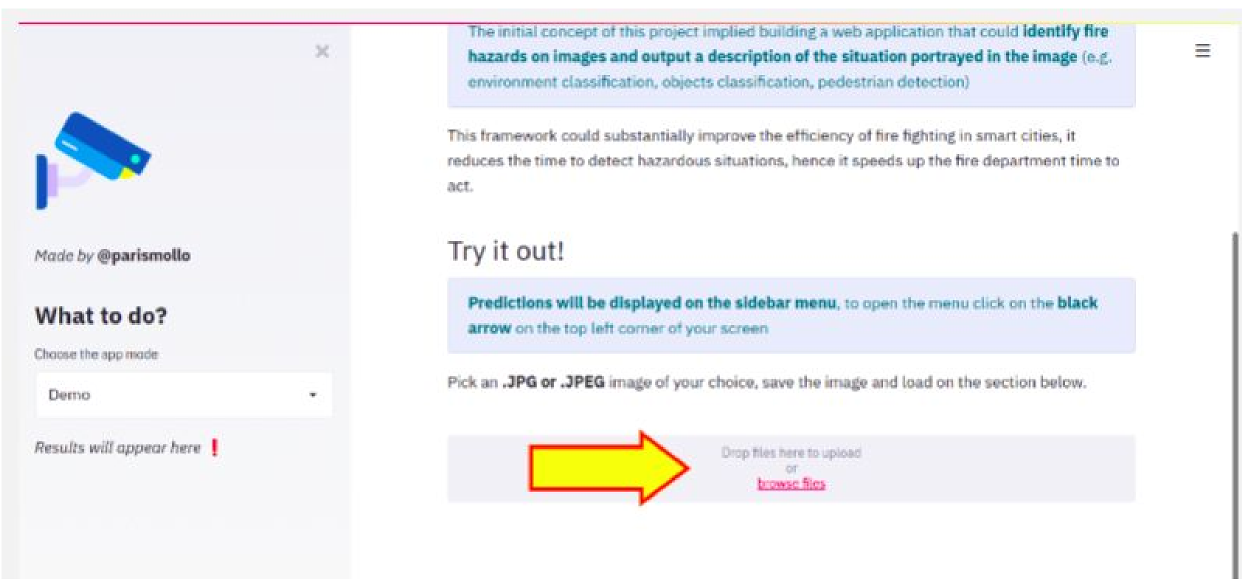
To test the project, access https://envai.herokuapp.com/ and wait a few seconds while the application boots. The landing page will have the necessary information to test the app and a description of the project. To test the machine learning models, go to the "Try it out Section" and load an image of your choice.

After loading the image, the app will start loading all the 4 models and this may take a while (a few seconds), once the models are ready a "success" message will appear on your screen and the results will appear on the left sidebar menu.

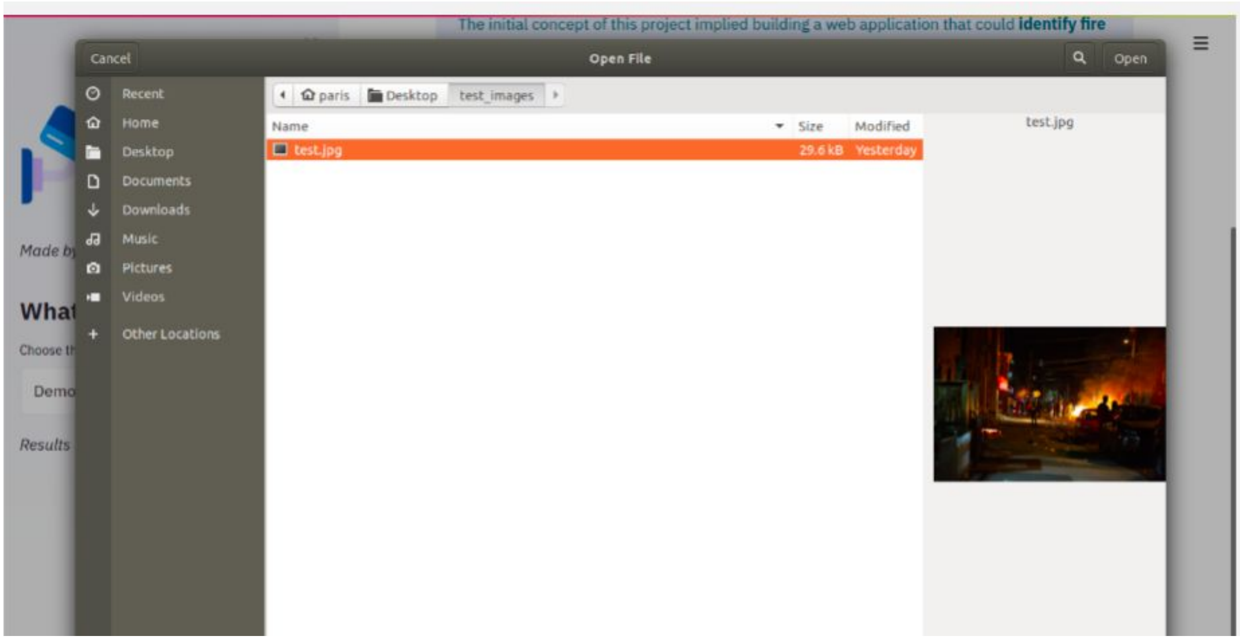
**Attention:** *If you are testing the app via mobile, the sidebar menu is by default closed, to open it, click on the top left black arrow.*



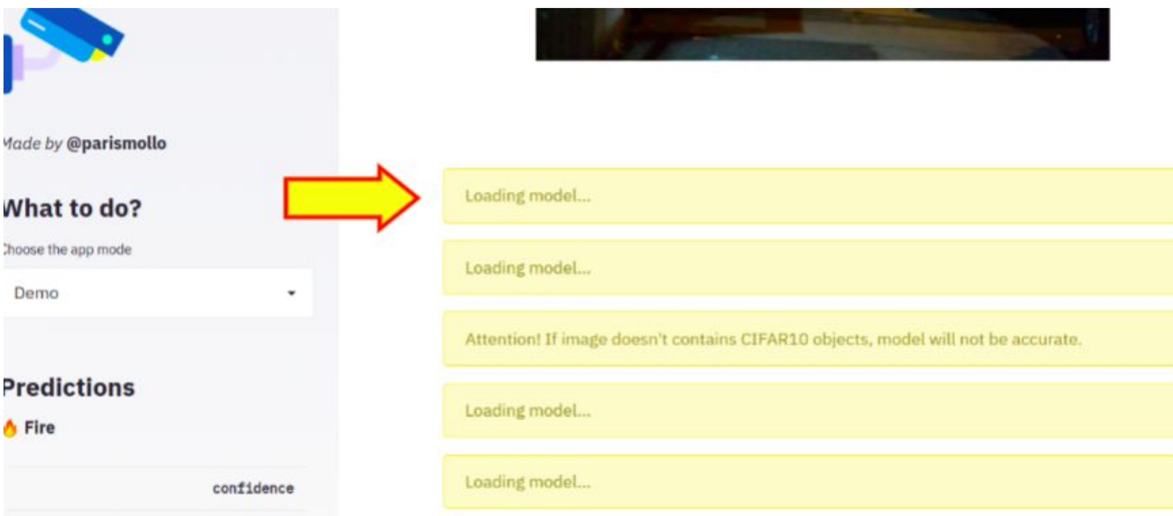

*Landing page - Tutorial*




*Insert images - Tutorial*




*Select image of your choice - Tutorial*




*Loading models - Tutorial*


*Predictions ready - Tutorial*


*Results - Tutorial*

# Part IV

## Conclusion

This report covered a few of the numerous challenges society faces nowadays in cities all over the world, such as transportation and mobility saturation, lack of security, and poverty. However, the development of the cities and the population's growth is likely to bring new challenges, above all, natural resource scarcity.

We've presented technologies that have the potential to tackle some of the urban challenges, apparently, at the current state, technology is the best candidate (alongside with other sciences) to bring innovation to cities and prepare the next generations to the development of intelligent cities. Nevertheless, it seems that bureaucracy, lack of trust, and poor understanding of technology by governments and city dwellers tend to be a difficulty and hold back the implementation of these new technologies and therefore the development of smart cities.

Computer Vision algorithms, such as CNN's model are on a promising path towards superhuman accuracy levels, with the increased number of available datasets and new machine learning techniques is likely that these kinds of computer programs will be a baseline for security frameworks of urban centers. However, the implementation of computer vision algorithms may also trigger another type of urban issue, this time, related to privacy.

I hope this report motivates and inspires you to chase and work towards the development of new solutions that can bring equality, peace, safety, health, and food to the hands of city dwellers around the globe. The smart city concept can be tempting and make it seem that technology, by itself, will be humankind savior, this is a misleading belief, only with smart humans, unequal and poor cities will transform into smart cities.

***The city of the future awaits you.*** Paris Mollo