The Story of Five MENA Cities: Urban Growth Prediction Modeling Using Remote Sensing and Video Analytics

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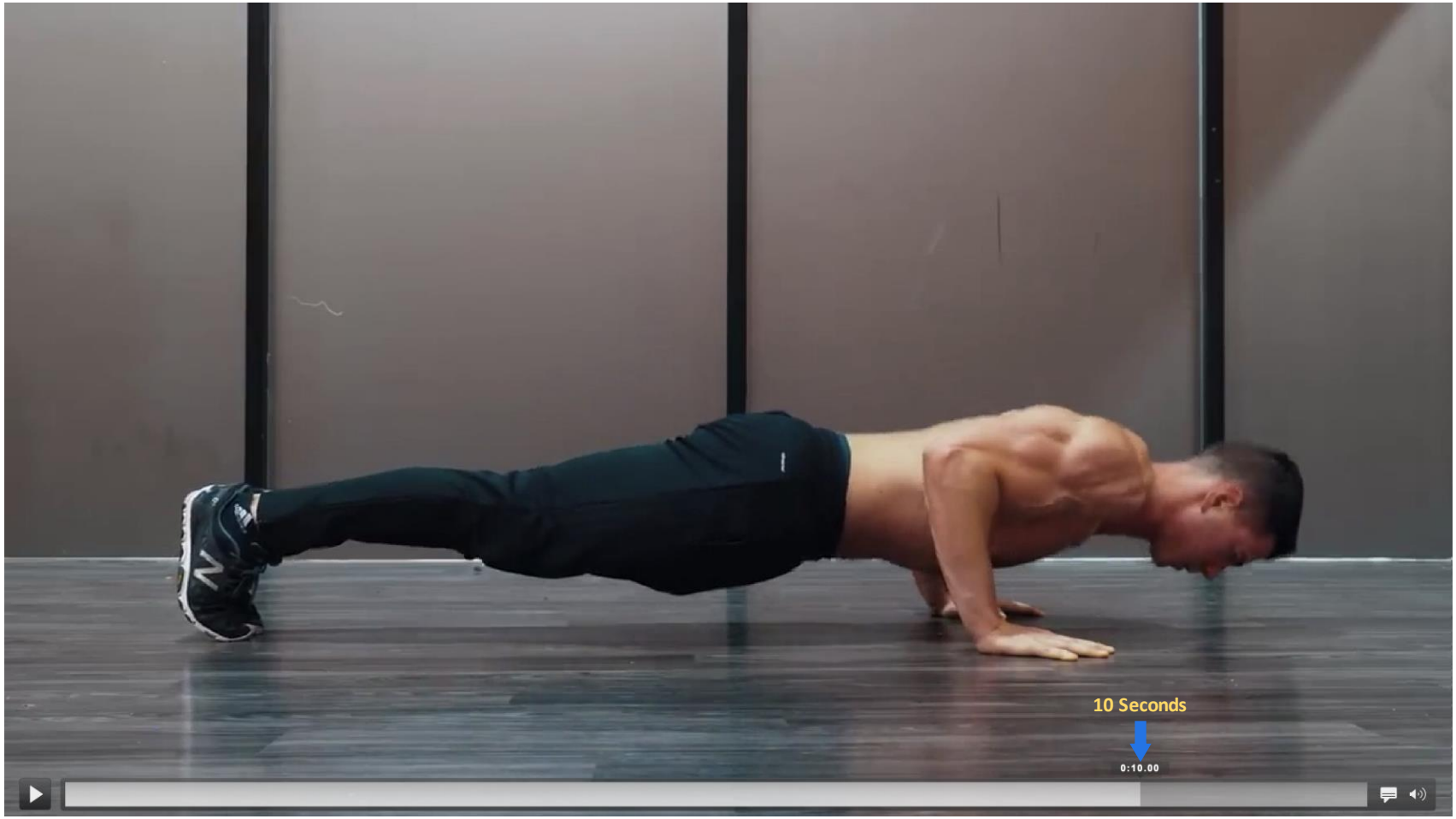
Presentation Outline

- Background
- Urban Growth Theories
- Challenges and Complexities
- UGPM - Supporting Technologies
- Modeling Framework
- Applications (Cairo and Casablanca)
- Learned Lessons

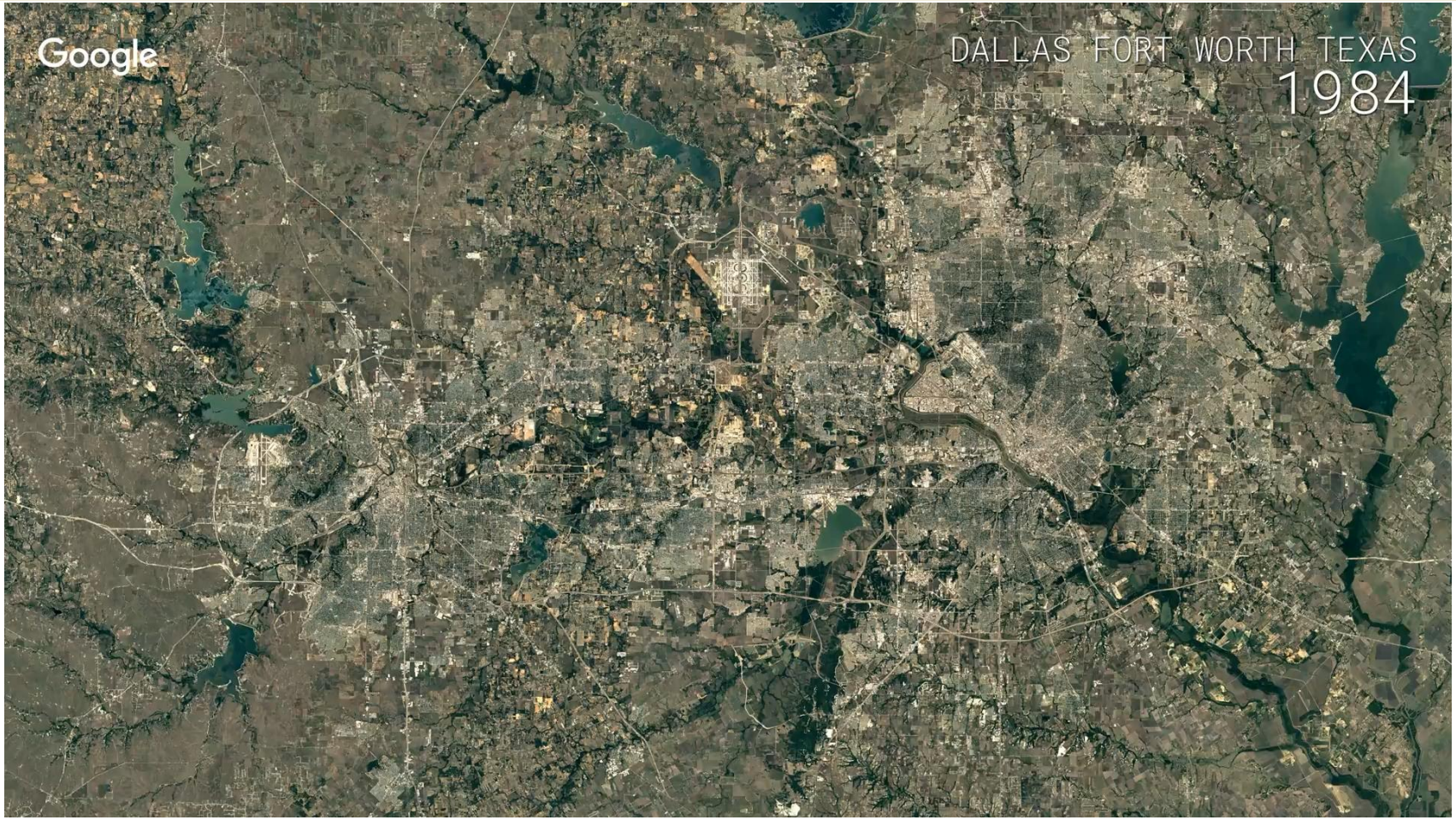
Video #1



Source https://www.calimove.com/

Push ups movement

Video #2



Source https://www.youtube.com/watch?v=znf3NcfGOoc

Google Timelapse: Dallas-Fort Worth urban growth

Background

- Cities have historically created vast economic opportunities and provided the required services to their citizens.

- Cities evolved from small concentrations around sources of fresh water to a dense fabric in the form of multiple interconnected centers.

The goal of studying growth pattern of cities/urban areas:

a) To **identify** directions and locations of potential growth.

b) To **assess** the infrastructure and public service requirements.

c) To **ensure** the integration of the new developments with the existing city structure.

d) **Deriving** effective policies that help achieve sustainable and economically-sound growth patterns.

Urban Growth Theories

Main theories for studying urban growth

Ecological theory

It models urban areas as ecological systems that naturally adopt to alterations in biophysical and socio-economic activities

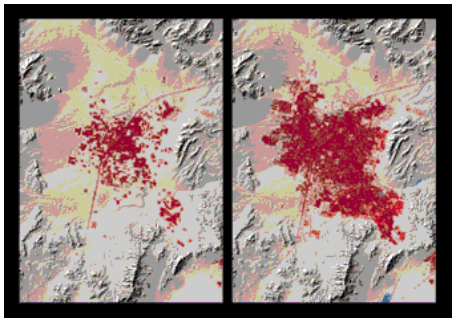
Machine theory

It views growth as the outcome of a deliberate planning process defined by the interactions among different stakeholders including policy makers, city planners, land developers and residents.

Machine theory is **widely accepted** as it explains many of the growth phenomena observed in urban areas. Also, it considered as one phase process that shapes the **long-term urban growth**.

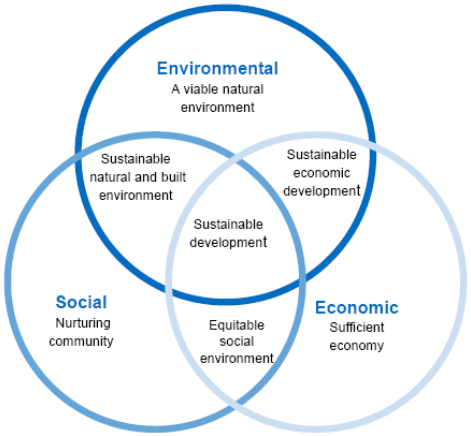
Challenges and Complexities

Challenges and complexities characterize the urban growth prediction problem:



- Urban growth is a dynamic non-linear process in both time and space that is difficult to represent in a closed analytical form.

- Most successful urban growth prediction models (UGPMs) have adopted simulation-based techniques that require considerable effort for model specification, calibration and validation.



- Urban growth prediction is normally impacted by many biophysical, socioeconomic and political variables that are in return difficult to obtain and/or predict.

Technologies Supporting UGPM Development

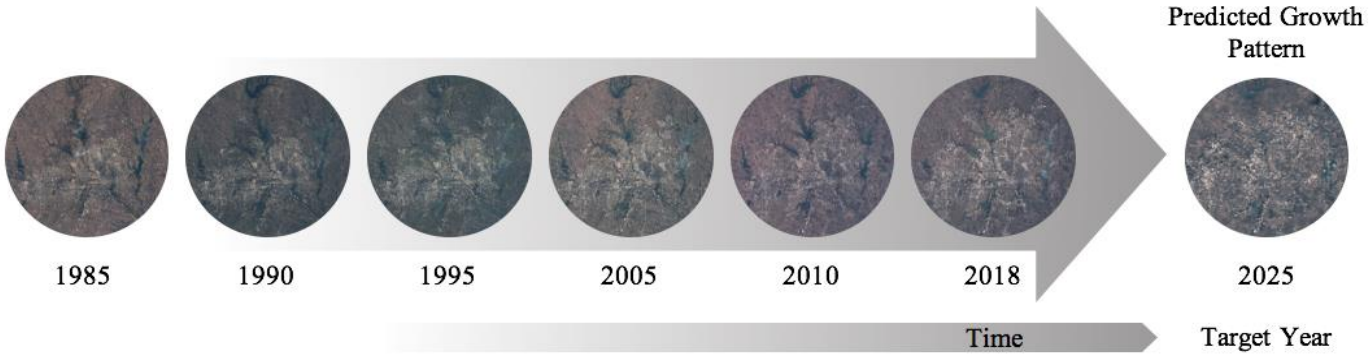
Satellite Imagery

- Provide information on land cover change over time, which can be used to retrieve reliable information on the time-varying growth pattern in urban areas.
- The richness and quality of the satellite imagery datasets open the doors for more comprehensive usage of these images to develop the next-generation UGPMs.

Machine Learning

- Several ML models have been proposed for developing UGPMs.
- For example, ANN/DNN have been adopted to overcome known limitations of regression-based models that are significantly impacted by the input data relationships.

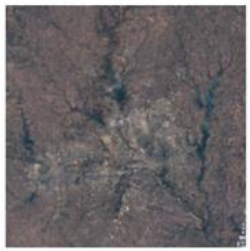
Video Prediction for UGPM



- The model adopts a Video Prediction approach as it treats successive satellite images recorded for an urban area over an extended past horizon as a video.
- The model is trained using historical satellite images to learn the spatiotemporal growth pattern (i.e., direction and rate of growth over time).
- The model obtains input an image x representing the urban area in base year $\boldsymbol{t}$ and a pre-defined prediction horizon.
- It constructs an image y that predicts the urban area for future year $\boldsymbol{t} + \Delta t$, using the learned historical growth pattern.

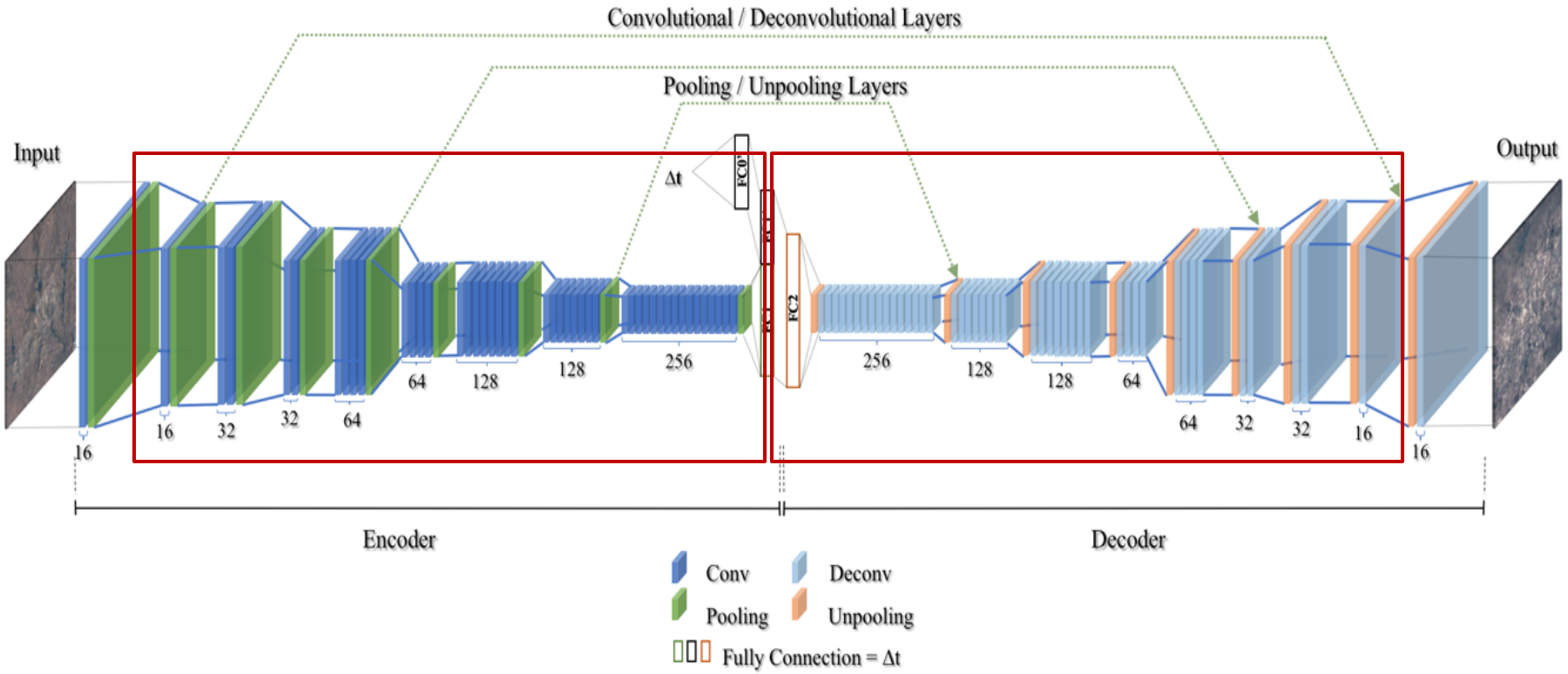
Data Preparation

Data structure for model training and validation

Image I_x	 1985	 1986	 1987	…	 Year t
Image I_y	 1987	 1991	 1995	…	 Year $t + \Delta_t$
Horizon	2 years	5 years	8 years	…	Δ_t

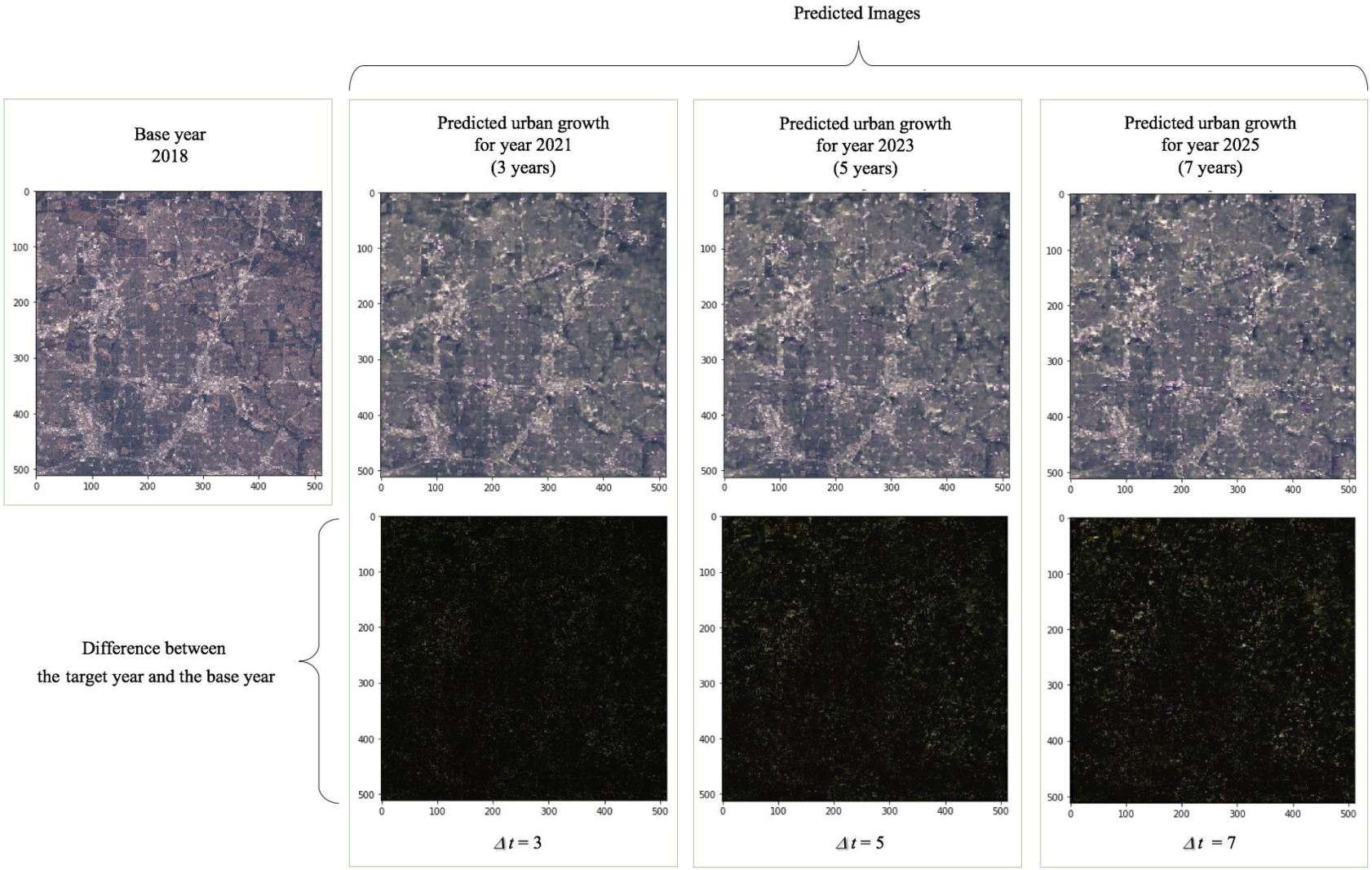
I_x: Input satellite image at time t I_y: output image at time $t + \Delta t$ Δt: the time difference in years between the two images

Time-Dependent Encoder-Decoder Architecture (TDED)



The Overall Structure of the TDED Model

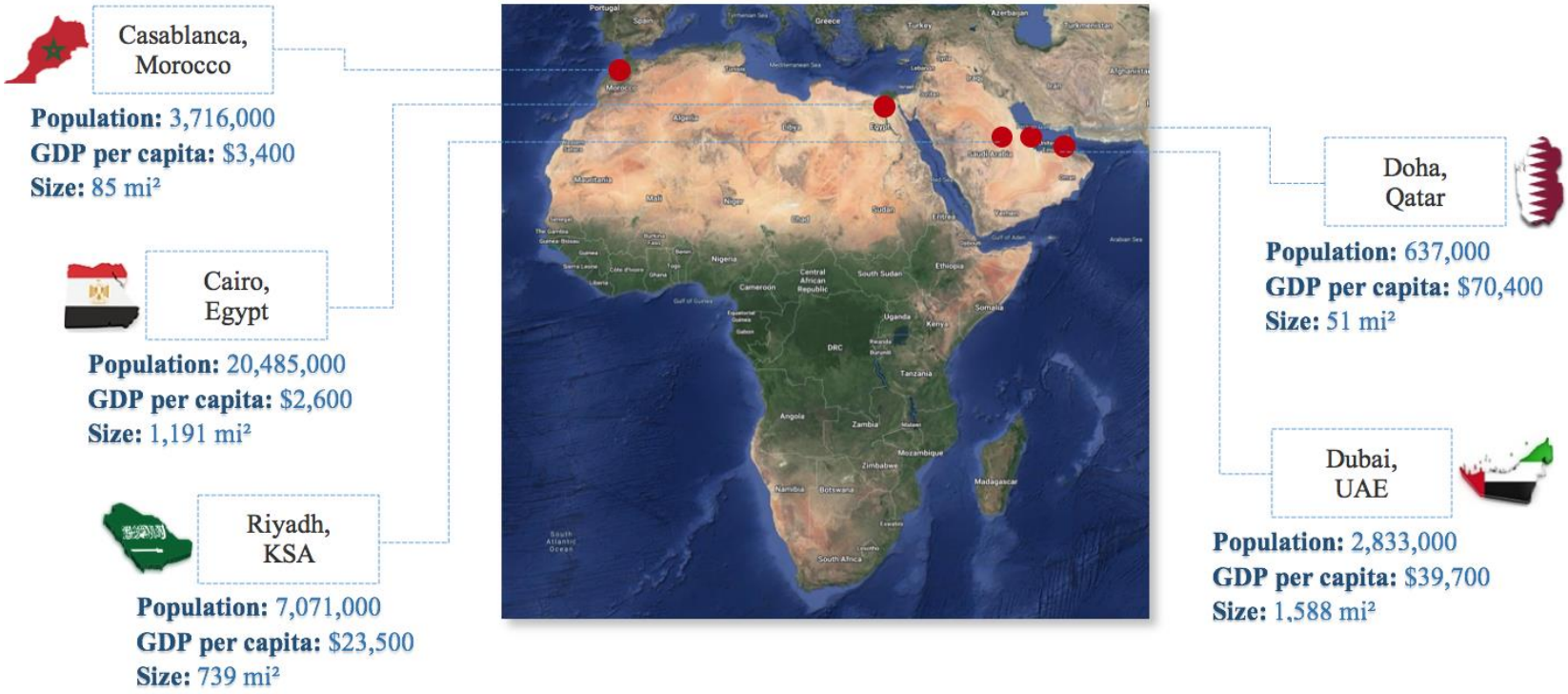
Application to Collin County, North Dallas



Urban growth prediction for Collin County after three, five and seven years considering 2018 as the base year

The Five MENA Cities

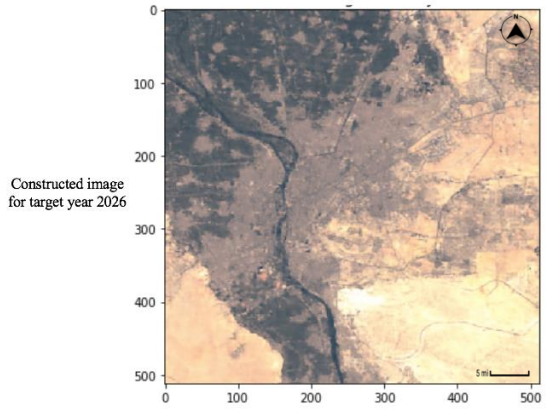
Summary of the selected MENA Cities

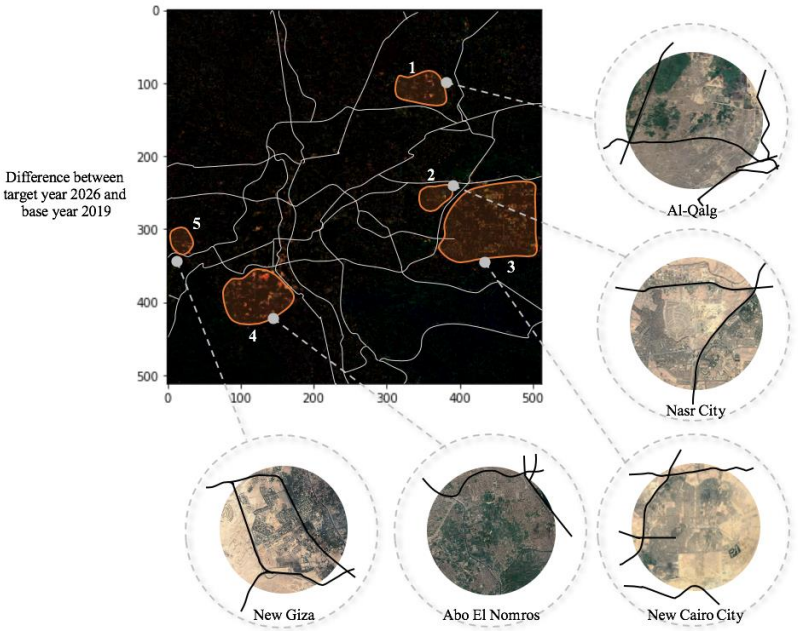


The Location of the Five MENA Cities

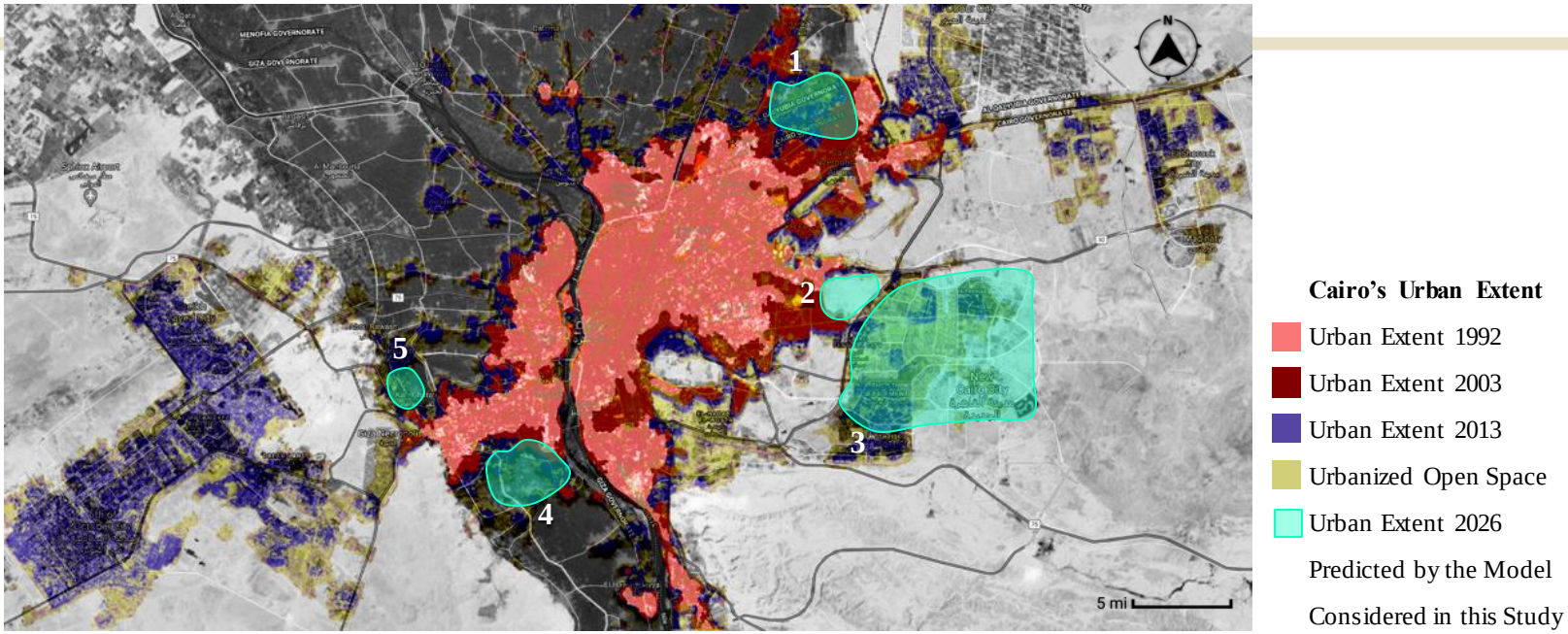
Urban Growth Prediction for the City of Cairo

Comparison between current and future urban growth of the city of **Cairo**





Urban Growth Prediction for Cairo (*Model Validation*)



Model validation and urban expansion of the city of **Cairo**. (Source: Angel et al., 2012)

The study is a collaboration between the NYU Urban Expansion Program at New York University, the United Nations Human Settlements Program (UN-Habitat), and the Lincoln Institute of Land Policy.

They adopt a data intensive approach extracted from satellite images and land use surveys to predict the urban expansion of the city **beyond 2013.**

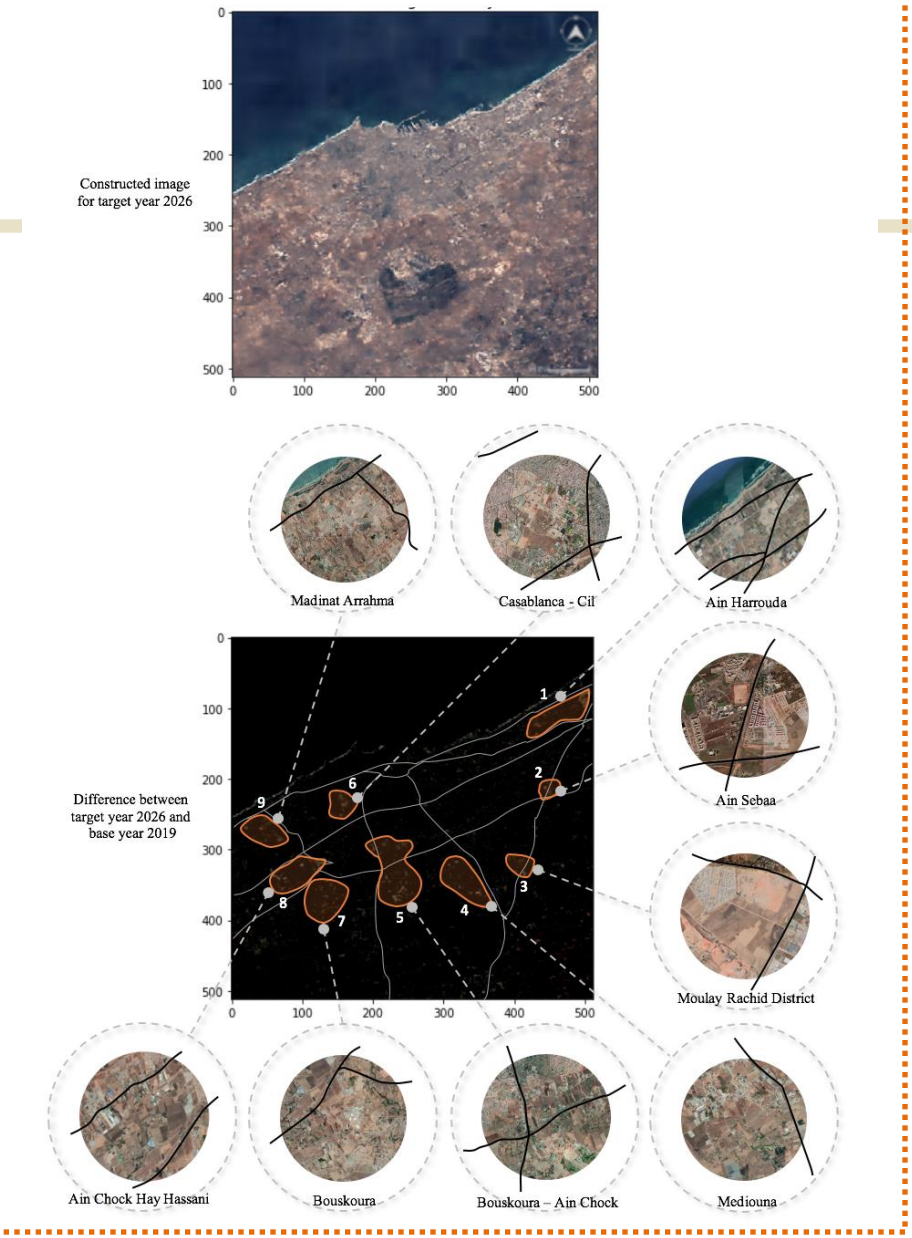
study is applied to a global sample of 200 cities (e.g., New York, Sydney, Montreal, Wuhan, Cairo, Riyadh) to map the spatial changes and urban expansion.

Main Observations:

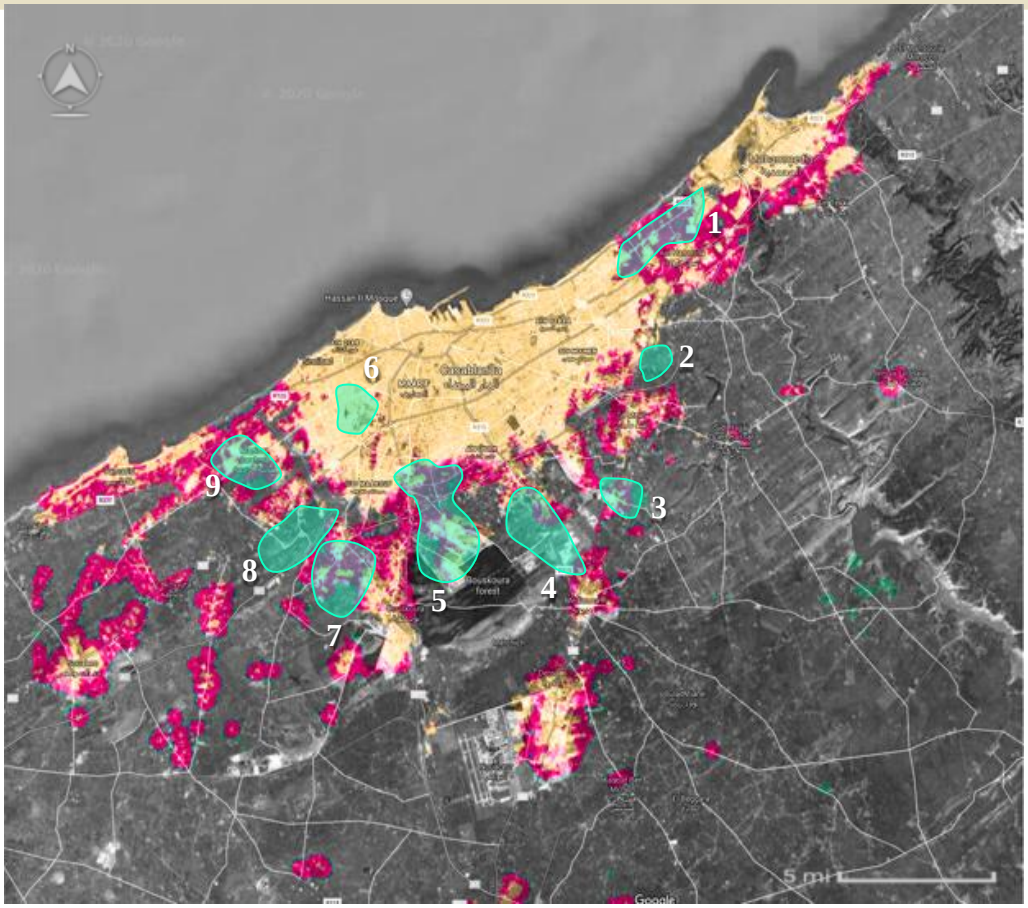
1. A **steady growth** towards the east and the west in the deserts.
2. The growth in the **east side** of the city, extends Cairo's boundaries with a new development in the east known as New Cairo.
3. This growth is supported by the **accessibility** provided by two main highways, namely, the Suez Rd. and the Ain El Sokhna Rd.
4. Similar **growth** in the western boundaries of the city known as New Giza.
5. The model predicts (disappearance of several agricultural pockets) in the north and the south of the Niles's Delta.
6. These **agricultural lands** surrounded by very high-density residential areas built on an agricultural land.

Urban Growth Prediction for the City of Casablanca

Comparison between current and future urban growth of the city of **Casablanca**



Urban Growth Prediction for Casablanca (*Model Validation*)



Probability of growth in year 2040 beyond the city's current boundaries .

SLEUTH cellular automata model.

Using satellite images from 1984 and 2018, and synthetic maps of urban growth of Casablanca **up to 2040**.

Casablanca urban growth map of 2040

Probability

- Base Urban
- 90% - 100%
- 70% - 90%
- < 70%
- Urban Extent 2026

Predicted by the Model Considered in this Study

Model validation and urban expansion of the city of **Casablanca.** (Source: Mallouk et al., 2019)

Main Observations:

1. Casablanca has prediction growth pattern similar to Dubai and Doha, the predicted growth is happening mostly inland and along the coast.

2. Two observations differentiate Casablanca from these two cities:

   All predicted growth zones are located at the city's current boundaries.

   Casablanca is an older city that is highly developed with limited vacant land available inside the city's current boundaries.

   The predicted peripheral growth is almost uniformly occurring in all directions around the city boundaries.

   The high population growth rates from inside the city combined with the intensive labor migration from the surrounding farms.

Learned Lessons

- The integration of the urban and the transportation planning processes for urban areas is critical for ensuring their sustainable growth.

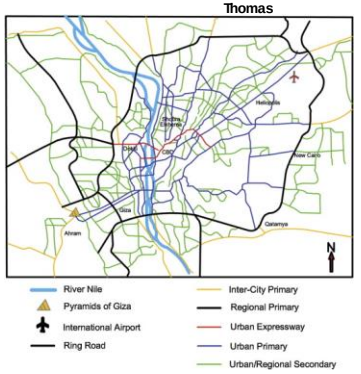
- While **ring roads** have been constructed to ease traffic congestion inside cities and to curb growth, But it has been shown an **ineffective** way to defining city boundaries and preventing its urban sprawl.

  For example, the city of Cairo continued to growth beyond its recently constructed ring road from almost all directions.

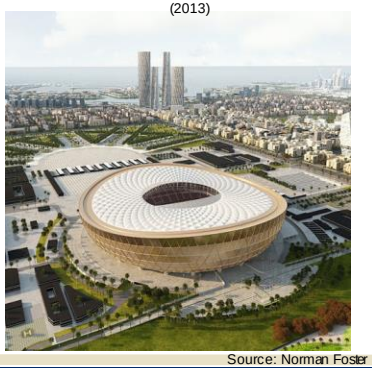
- Careful attention needs to be given to the planning of mega projects in urban areas.

  For example, most urban developments predicted in the city of Doha are triggered by nearby new mega projects planned in the city.

Source: **Jordan Thomas**



Source: Huzayyin & Salem (2013)



Source: Norman Foster

Learned Lessons (Cont'd)

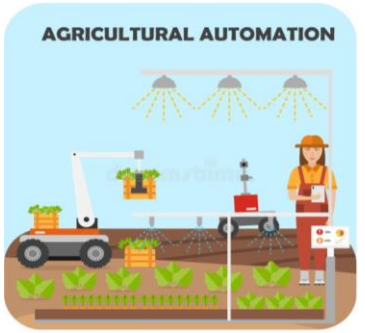
- There is always great benefit in diversifying housing options within the city to prevent urban sprawl.

  For example, the expedited urban sprawl observed in the city of Riyadh is primarily contributed to the high preference of most households to live in a single-family home, even in the case of small family sizes.

  Housing policies and incentives that encourage small households to live in apartment buildings and townhomes could help in curbing the sprawl observed in the city.

- The migration is mainly due to **increasing agricultural automation** and the **lack of alternative job opportunities** for the traditional agricultural labor.

  As observed in the cities of Cairo and Casablanca, Which resulted in the creation of **slums** and **neighborhoods** with no adequate services.



Learned Lessons (Cont'd)

- Urban growth could occur at the expense of valuable natural resources within or surrounding the city.

  For example, the city of Cairo has been growing at the expense of high-value agricultural land on the north and the south boundaries.

  Similarly, the growth in Dubai and Doha is reported to be occurring at the expense of green space within these cities.

- Strict **regulations** and **incentives** are required to prevent such a growth pattern to ensure that valuable natural resources are preserved.

THANK YOU