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URBAN RESEARCH
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REPORT
06

CITY SCANNER BEIRUT

Drive-by Solution to Assess Pollution Related to the Demolition and Reconstruction of Beirut

LCAU
NORMAN B. LEVENTHAL CENTER FOR ADVANCED URBANISM

MIT

Since 2019, the Dar Group and MIT have collaborated on an initiative to catalyze innovative, interdisciplinary research that addresses the design and planning of new and existing urban landscapes in the MENA region, and other comparable arid, semi-arid regions. Through the Dar Group Urban Seed Fund at MIT Norman B. Leventhal Center for Advanced Urbanism and organized through two seed grant calls, the Dar Group has supported nine research projects undertaken by faculty and students from MIT's School of Architecture and Planning. In the first seed grant cycle, projects presented a wide range of research interests addressing equitable heat-resilience at the neighborhood scale to advanced manufacturing of structurally optimized concrete housing. In the second seed grant round research focused on various facets of the recovery, planning, and reconstruction effort in Beirut. These reports share the findings of the nine research projects.

With thanks to the Dar Group for their generous support of this research endeavor, with specific acknowledgment to Mustapha Madi and Daniel Horner for their continued support, guidance, and collaboration.

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Carlo Ratti, Fábio Duarte,
and Simone Mora

CITY SCANNER BEIRUT

Drive-by Solution to Assess Pollution Related to the Demolition and Reconstruction of Beirut

EXECUTIVE SUMMARY

- Designed and fabricated three low-cost environmental sensing platforms (City Scanners)
- Calibrated and validated City Scanners with research-grade monitors in both Boston and Beirut
- Deployed City Scanners on taxis in Beirut over four months
- Collected more than 60,000 air pollution measurements including particulate matter, CO + SO_2 gases, and noise
- Held workshops on coding and ethics of data-driven solutions for students at The American University of Beirut (AUB)

6.1 INTRODUCTION

Located in a resource-scarce developing country, the air pollution profile of Beirut is unique and concerning at its current stage. There are two identified major sources of air pollution in Beirut: diesel generators and light-duty vehicles. Lebanese heavily rely on diesel generators to fulfill their daily electricity needs due to a constant electricity supply shortage. The unmet power supply by Électricité du Liban is increasing over the years, from 22% in 2008 to 37% in 2018— and it is projected to grow to 56% in 2026. It is estimated diesel generators consumed 1.6 million tons of fuel and emitted about 2 Gg of fine PM in 2016. Meanwhile, the number of light-duty vehicles doubled over the course of a decade (from 2007 to 2016) and are currently emitting 0.2 Gg fine PM annually. Both emission sources are local, distributed, and follow a strong diurnal pattern. Therefore, we propose to assess the air quality effects of diesel generators and light-duty traffic in Beirut by deploying drive-by-sensing solutions to complement traditional technologies of environmental monitoring.

We have developed a sensing platform to be mounted on any vehicle, allowing the capture of spatiotemporal variations of environmental phenomena in urban areas at a high granular scale. City Scanner (http://senseable.mit.edu/cityscanner) is a low-cost, solar-powered, and modular vehicular sensing platform that mounts different sensors, such as Optical Particle Counter (OPC), CO and SO_2 gas sensor, sound pressure, and temperature and humidity sensors. Deploying City Scanner sensing nodes and gathering high-quality datasets enable decision-making and foster public engagement on environmental issues. This pilot project is envisioned as the spearhead of a larger initiative to monitor air quality in other cities in the Middle East.

Our original proposal focused on examining air pollution originating from construction and demolition waste and induced traffic from the reconstruction of Beirut's port area following the massive explosion in 2020. However, due to restrictions in accessing the areas affected by the demolition and reconstruction, we pivoted the proposed study to capture the air quality effects of diesel power generators and local traffic. This decision was made following the recommendation of environmental science experts at AUB and supported by local stakeholders at the DAR office in Beirut.

Figure 1. *MIT-SCL City Scanner sensors opportunistically deployed on the roof of three taxis in Beirut [Source: Professor Issam Lakkis, AUB, 2022.]*

Key Objectives

1. Collect high-fidelity, hyperlocal air quality data in data-scarce Beirut
2. Link and assess the effects of diesel generators and car traffic on local air quality
3. Identify and examine the causes of local air quality hotspots
4. Develop a robust exposure surface to understand the spatio-temporal pattern of air pollution
5. Assess potential public health outcomes and regional disparities

Objectives in Detail

City Scanner Beirut is envisioned as a tool capable of helping experts in Beirut meet basic benchmarks in atmospheric monitoring. It is designed to ameliorate shortcomings in data collection by providing accurate air quality measurements local to the city and specific to its residents. Sensors are installed to draw correlations between diesel generators, car traffic, and public health, with resultant data mapped to make legible trends in spatio-temporal use and emissions. Data amassed is intended to aid in assessments of public health and quality of life standards across the region.

6.2 PROCESS

The low-cost environmental sensing platform evaluated in this study was developed as part of the City Scanner initiative at the Senseable City Lab, Massachusetts Institute of Technology. For simplicity, the sensing platform is referred to as the 'City Scanner' or 'CS' hereafter. Each CS unit is equipped with an Alphasense OPC-N3, an Alphasense CO-A4, and an Alphasense SO_2-A4 that measure particle counts, nitrogen dioxide, and sulfur dioxide. Specifically, Alphasense OPC-N3 is an optical particle counter that has a nominal monitoring range from 0.35 to 40 micrometers. It has been widely adopted in multiple previous publications and holds a record of proven accuracy and robustness. It provides particle counts in 24 size bins and estimates PM_1, $PM_{2.5}$, and PM_{10} mass concentrations based on presumptions of the particle shape and density. Alphasense CO-A4 and SO_2-A4 are electro-chemical gas sensors that can operate in a variety of ambient environments, but are known for their cross-sensitivity issues with NO, CO_2, and O_3. The gas concentration readings are given as electric signals (millivoltages) and need to be converted to volume concentration. The low-cost sensors are integrated into the City Scanner, which is a standalone sensing platform with data storage and remote monitoring capability. The platform is powered by a battery that can be charged through a power supply or a solar panel. The data from the sensors are stored on an on-board SD card, which can be accessed remotely through an LTE connection for routine checks on the data and status of the device.

In total, three CS units were deployed on taxis circulating in Beirut in a staggered way from February 16 to June 30 (Figure 1). Specifically, they were in operation from February 16 to May 19, April 12 to May 12, and April 26 to June 30, respectively. CS units were synchronized using GPS timestamps to yield readings every ten seconds. In total, 60,000 raw 10-second records were collected across Beirut. Raw 10-second records were calibrated against a research-grade particulate matter monitor provided by AUB for three weeks beginning on July 27, 2022. The Met One Instruments E-BAM Portable Environmental Beta-Attenuation Mass Monitor was used, whose accuracy is consistent with U.S. Environmental Protection Agency's requirement for Class III $PM_{2.5}$ and PM_{10} measurement. Calibrated 10-second readings were filtered by several initial criteria before they were further analyzed. About 50% of data were excluded in the process, mainly due to high relative humidity (>90% or raining) and extreme readings (< 1 ug/m^3 or >1000 ug/m^3 for $PM_{2.5}$, < 200 mv or > 900 mv for CO_2 and SO_2 electro-signal).

Figure 2. *Calculation of MIT-SCL City Scanner Air Quality sensors on the roof of The American University of Beirut [Source: Simone Mora, MIT, 2022.]*

After calibration, mean and median $PM_{2.5}$ values in Beirut were measured at 53.4 and 27.1 ug/m^3, respectively, during the sampling period. The values for PM10 are 122.7 and 53.1 ug/m^3. As a reference, mean $PM_{2.5}$ and PM_{10} levels across the U.S. are 8.4 and 59.9 ug/m^3 in 2021. Spatial coverage of CS measurement in Beirut are mapped in Figure 3, along with spatial distributions of $PM_{2.5}$ and PM_{10}. The severe air pollution complex in Beirut is worth exploring from many fronts, of which the most prominent one is diesel generator usage.

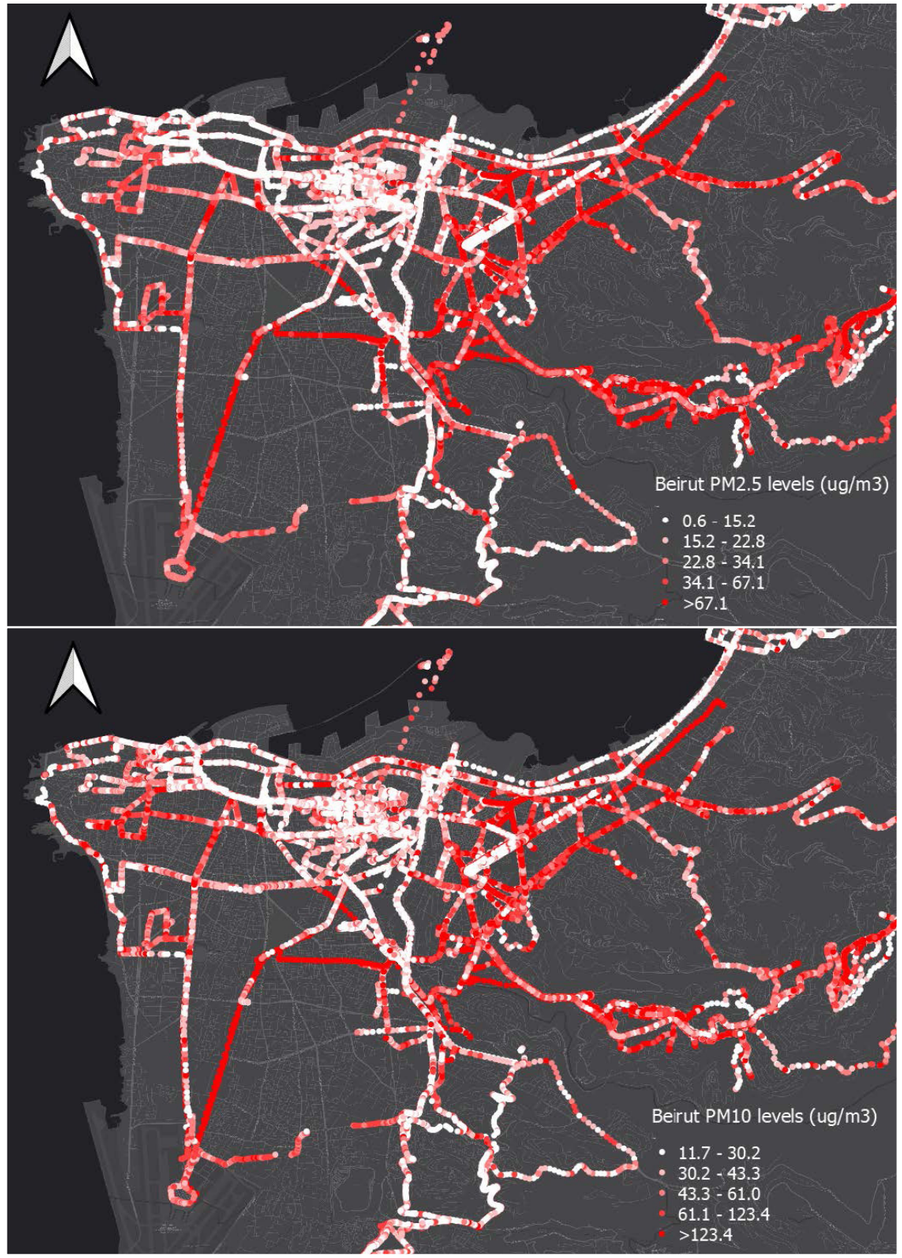

Figure 3. *Spatial distributions of (a) PM2.5 and (b) PM10 in Beirut [Source:Carlo Ratti and Fábio Duarte, City Scanner Beirut, 2022.]*

We observe that the most polluted neighborhoods are located east of Beirut, as shown in Figure 4, rather than in the dense city environment. This agrees with a priori experience from the locals and the previous findings from our AUB partners' paper using a computational fluid dynamics model to predict air pollution distribution. It is attributed to the fresh air brought by the dominant wind that lowers the within-city $PM_{2.5}$ concentrations but increases trans-neighborhood dispersion during the mobile monitoring season. Temporally, the highest $PM_{2.5}$ concentrations are observed in the morning, beginning as early as 4 a.m. It is partially induced by the peak hour traffic in the morning. The association between deteriorated air quality and diesel generator usage still bears further investigation.

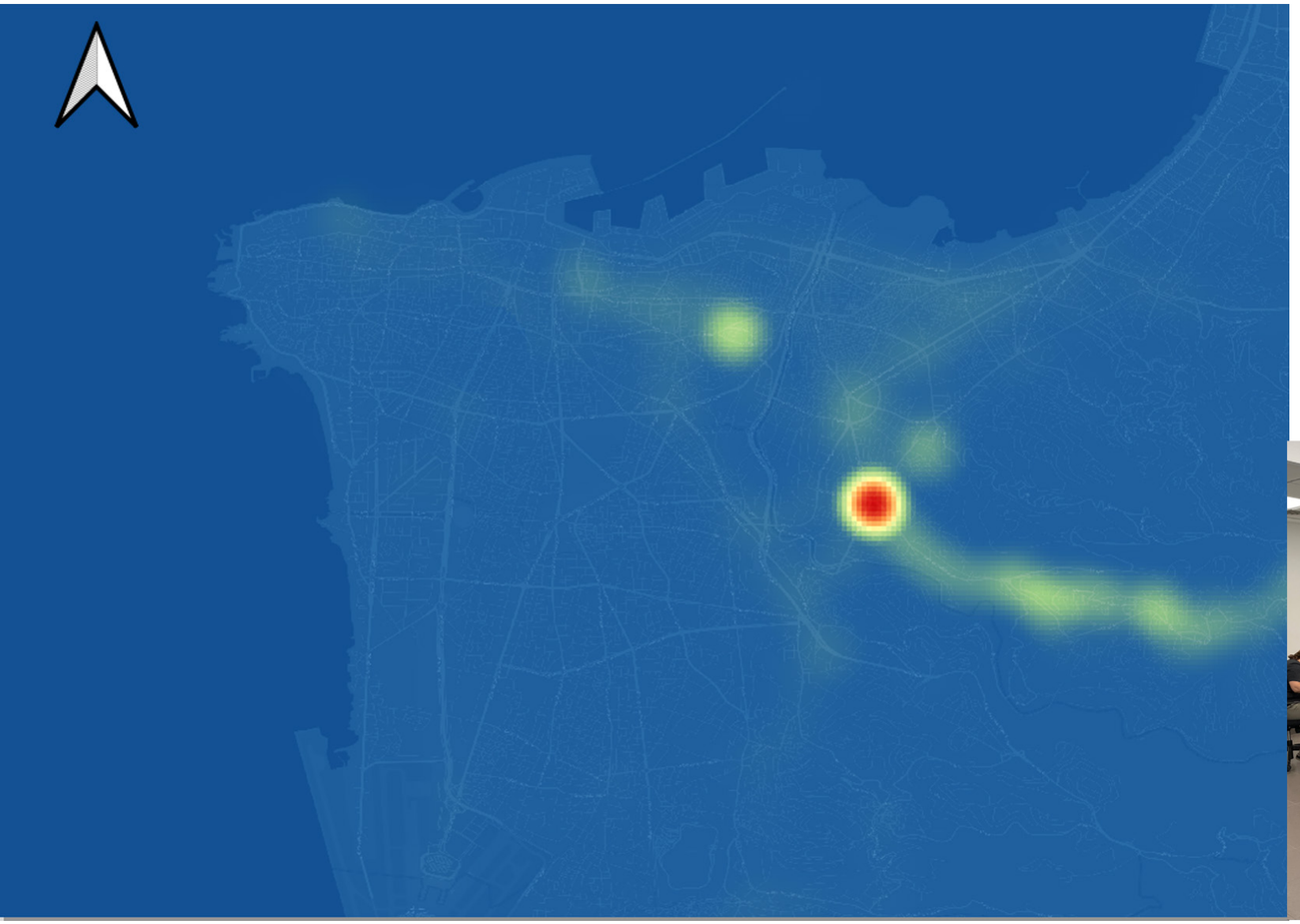

Figure 4. *PM2.5 hotspots in Beirut [Source:Carlo Ratti and Fábio Duarte, City Scanner Beirut, 2022.]*

6.3 OUTCOMES

Summary of Outcomes

1. 360 hours (60,000 raw data points) of opportunistic air quality measurements (PM1, PM2.5, PM10, SO2, CO, temperature, humidity, noise) calibrated against research-grade sensors
2. Local air quality hotspot mapped and analyzed
3. Exposure surfaces for local air pollution identified
4. Coding workshop with faculty and students at AUB aimed at providing them with tools to conduct environmental analyses developed and executed

Outcomes in Detail

City Scanner managed to successfully collect and analyze 360 hours of air quality data gathered throughout its period of installation in Beirut. Our team managed to design and fabricate three low-cost sensing units calibrated to screen levels of particulates including PM1, PM2.5, PM10, SO2, CO, temperature, humidity, and noise. They were mounted to taxis between February and June 2022, and collected data points in 10 second intervals. While it is hypothesized that the severity of air pollution in Beirut is owed in large part to emissions from diesel generators, their impact could not be confirmed by our findings alone. Regardless, we were able to confirm that Beirut's most polluted neighborhoods are located to the east of the city, with air pollution peaking in the mornings alongside rush hour vehicular traffic. A concluding lecture and workshop were given at The American University of Beirut to demonstrate the assembly and usage of the scanners

Next Steps

Future iterations of this project will work to more closely analyze the relationship between deteriorated air quality local in Beirut and its relationship to the reliance of diesel-powered generators by residents across the city. Working on increasing the fidelity of data collected in the outskirts of Beirut's metropolitan area is also worth probing further, as the taxi routes utilized depended—and varied heavily—on passenger destinations and demand. Also of importance to the City Scanner project is the installation of further sensors in similarly data-scarce cities across the region. Developing larger, more robust analyses of air quality across the region will help experts map out trends in public health in the long run.

Figure 5. *Ideation and coding workshops performed with students at The American University of Beirut [Source: Simone Mora, MIT, 2022.]*

Outputs

Manuscripts drafted for peer review:

An Wang, Simone Mora, Fabio Duarte, Issam Lakkis, and Carlo Ratti. “Investigating local air quality effects of diesel generators with low-cost sensing nodes in Beirut.” 2022.

Background Intellectual Property:

- City Scanner Sensing Platform v2.0 TLO case number 23120
- City Scanner Sensing Platform v1.1 TLO case number 22468
- City Scanner Sensing Platform TLO case number 21787

Broader Impacts

- The results of City Scanner Beirut have proved the prototypes adept at collecting various types of urban air particulates for analysis by experts of the cities in question
- The sensing platforms designed and fabricated for the project are low-cost enough to be deployed across cities of interest around the world
- The data collected during this project period can help map larger trends in air quality and standards of living both across Beirut and the region
- City Scanner Beirut can help mitigate issues exacerbated by data scarcity as they relate to charting public health progress and crises
- With the proper deployment methods, City Scanner aids in identifying the impact of particularly problematic sources of emissions and provides the evidence to properly address their impact
- The workshops held in conjunction with this phase of data collection equip young and established professionals with the skills necessary to deploy and develop further rounds of atmospheric monitoring and evaluation

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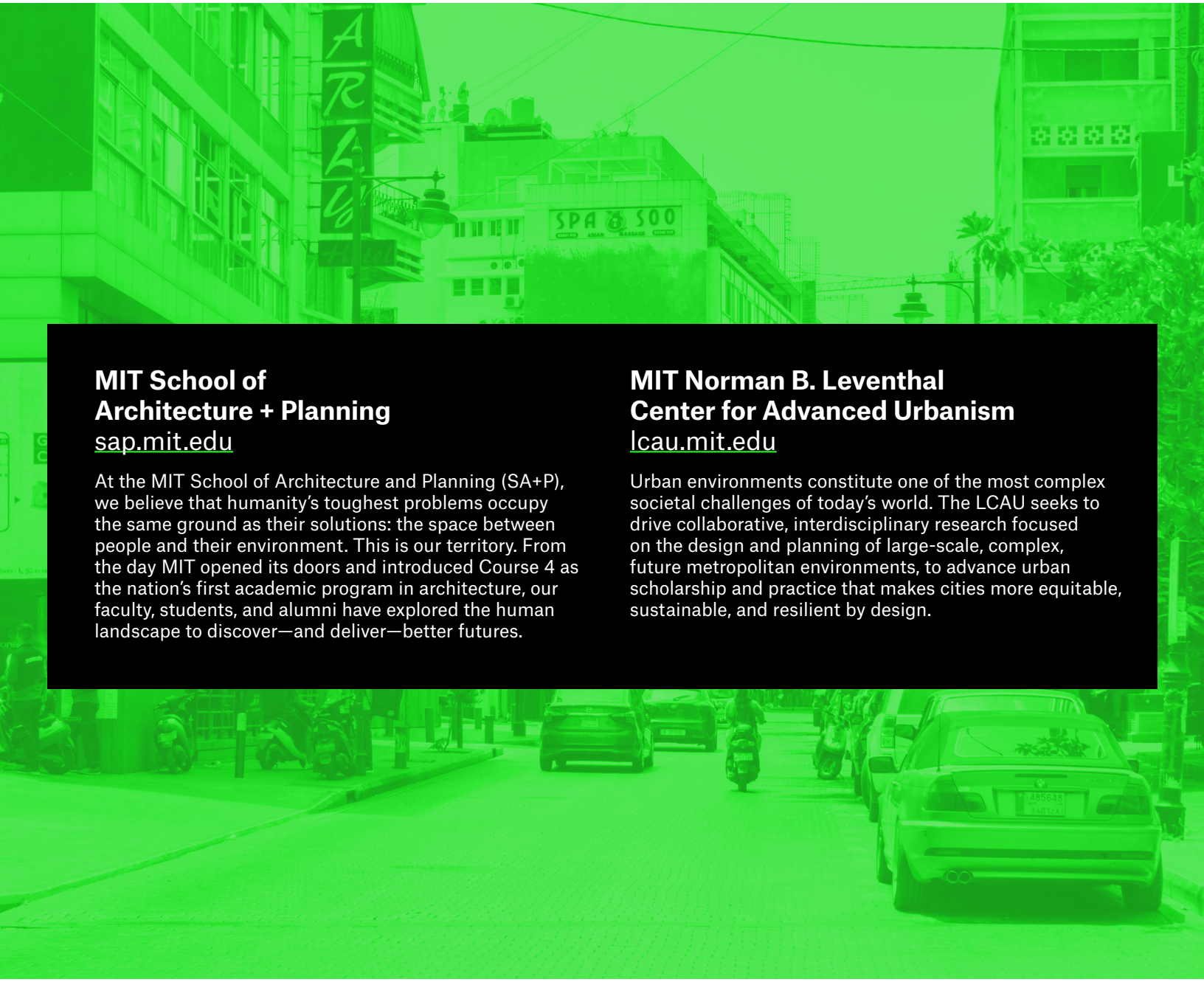

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