Prefabricated Smart Concrete Road Structures for Sustainable and Smart-city Development of Hong Kong

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- **Content**
  - Introduction
  - Prefabricated Structures
  - Surface-induced Smart Porous Pavement
  - Surface Textures for Skid Resistance and Noise Abatement
  - Energy Harvesting from Pavement Surface
  - New Pavement Surface for Safety Improvement
  - Pavement-based Vehicle Position System
  - Automatic Prefabrication and Construction
  - Conclusion and Future Perspectives

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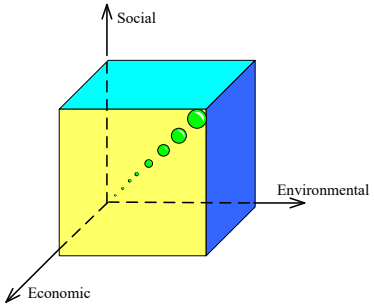
This research is supported by the Research Impact Fund

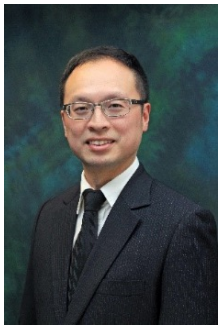
from Hong Kong Research Grants Council.

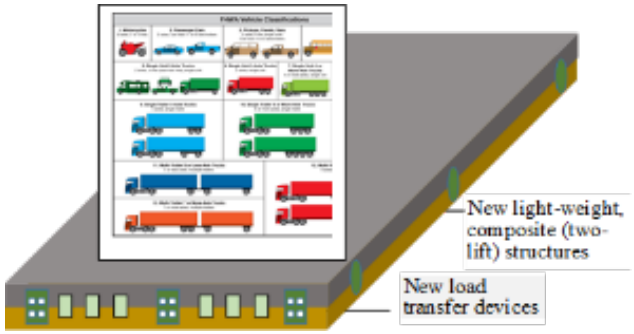
Our Research Team: Professors



Professor S. Thomas NG
HKU

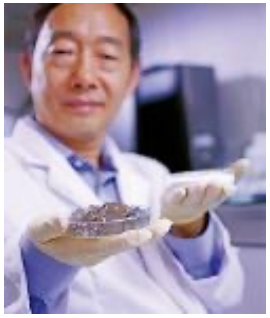
Sustainability Assessment

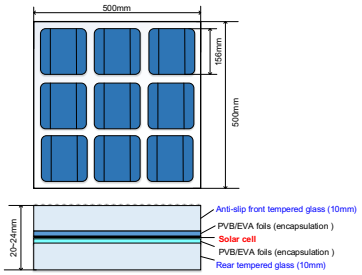




Dr Tak-Ming Chan, PolyU

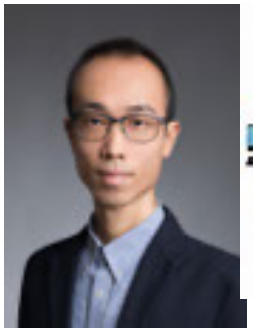
Prefabricated Structure





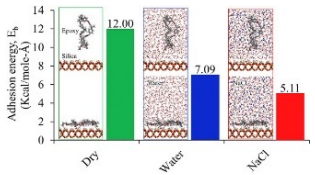
Prof. Hong-xing, Yang, PolyU

Energy harvesting



Prof. Edward Chung, PolyU Prof. C. K. Michael Tse, CityU Dr. Ivan Ho, PolyU

Smart Systems



Dr. Denvid Lau, CityU

New Materials

The Hong Kong Polytechnic University
香港理工大學

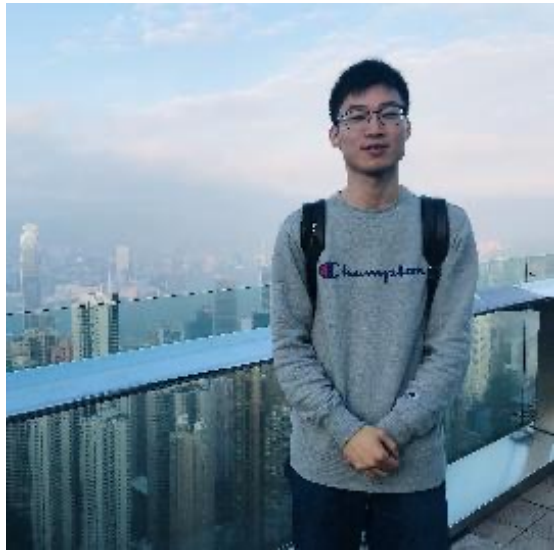
嘉華建材
K.WAH CONSTRUCTION MATERIALS
嘉華集團成員 A member of K. Wah Group

CHEC
中國港灣工程有限責任公司
香港代表： 振華工程有限公司
CHINA HARBOUR ENGINEERING COMPANY LIMITED
HONG KONG REPRESENTATIVE: ZHEN HUA ENGINEERING CO., LTD.

Our Research Team: Postdoctoral Fellow, PhD and Mphil students (A partial list)

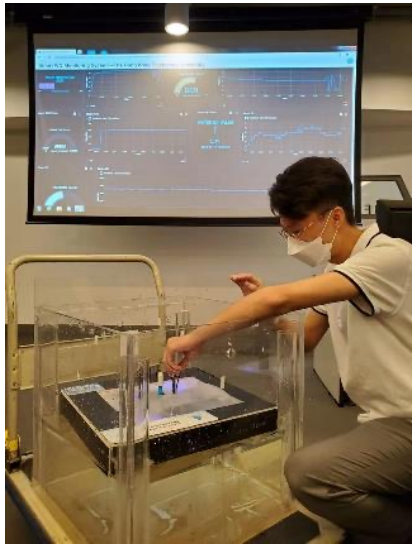
Dr. Shicong Mo
(Postdoctoral Fellow)

Mr. Wei Sheng



Mr. Jiachen Guo

Mr. Eric Lee



Mr. Yuhao Wang

Introduction

- In many urban areas, pavements and roofs constitute over 60% of urban surfaces (Akbari et al. 2009; Rose et al. 2003).

Metropolitan Areas	Vegetation	Roofs	Pavements	Other
Salt Lake City	33.3	21.9	36.4	8.5
Sacramento	20.3	19.7	44.5	15.4
Chicago	26.7	24.8	37.1	11.4
Houston	37.1	21.3	29.2	12.4

>26.5% total land in the Tsim Sha Tsui district is covered by pavements.

In Hong Kong, about 16% of roads are surfaced with concrete pavements.

Source: Akbari, H., Menon, S., & Rosenfeld, A. (2009). Global cooling: increasing world-wide urban albedos to offset CO 2. Climatic change, 94(3-4), 275-286.
Rose LS, Akbari H, Taha H (2003) Characterizing the fabric of the urban environment: a case study of Greater Houston, Texas. Lawrence Berkeley National Laboratory Report LBNL-51448, Berkeley, CA

Introduction

- Land is a very valuable resource for cities.
- Comparatively, pavement cost is relatively less.
- Yet, pavement design and construction practices in cities essentially follow those in rural areas.
- And the majority of roads are surfaced with bituminous pavements.

Problems of Current Urban Pavements

- Structure Durability.

Pavement Rutting Due to Slow and Heavy Traffic

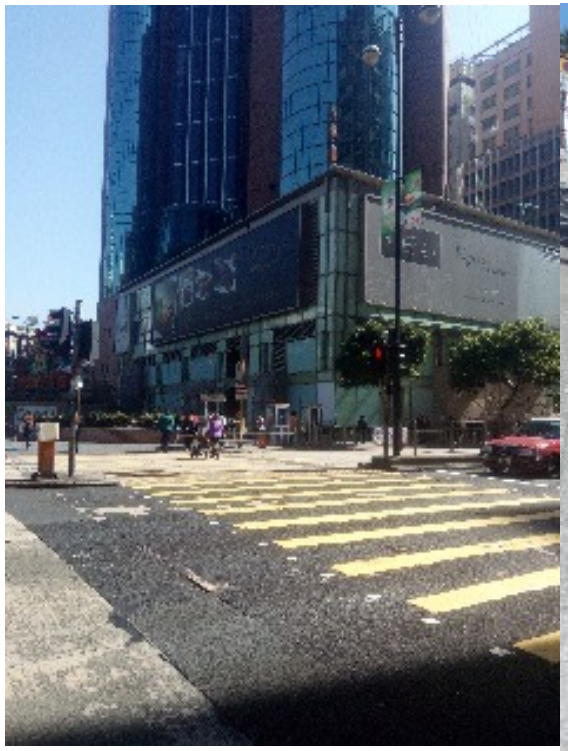
Location: Lung Mun Rd., Hong Kong

Pavement Fatigue Cracking Due to Heavy Traffic

Location: Tun Mun Rd., Hong Kong

Problems of Current Urban Pavements

- Surface Durability.



Loss of Concrete Surface Coating

Location: Mong Kok, Hong Kong

Raveling of Porous Pavement

Location: Hong Kong Island, Hong Kong

Problems of Current Urban Pavements:

- Difficult to close main roads for repair and maintenance.

Pavements after "Quick" Repairs

Location: Causeway Bay, Hong Kong

Pavements after "Quick" Repairs

Location: Causeway Bay, Hong Kong

Problems of Current Urban Pavements:

- The urban environment poses unique constraints on construction methods.

Work is often done manually

Tight construction schedule

Complaints from residents on noise, dust, and smell

Problems of Current Urban Pavements

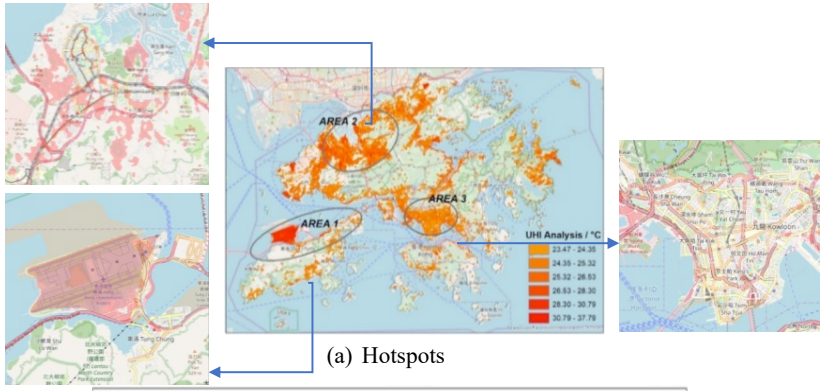
- From 2008 to 2017, HK recorded an annual average traffic casualty of 19,681, resulting in approximately 120 deaths;
- Some of these traffic accidents may be associated with road construction zones, inadequate skid resistance, pavement rutting, wet weathers, and low visibility.

Problems of Current Urban Pavements:

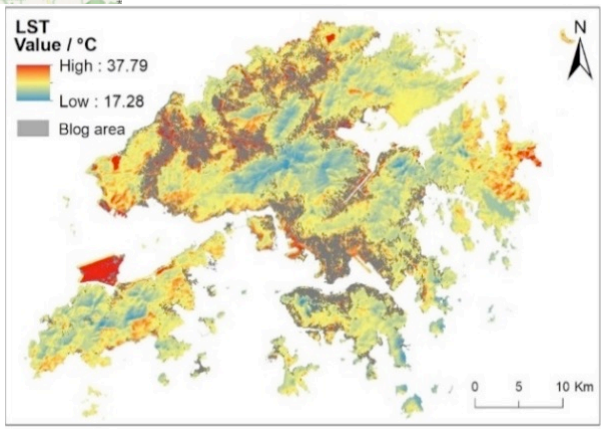
- In cities, buildings adjacent to busy roads are affected by traffic noise.

Problems of Current Urban Pavements

- Conventional pavements are usually impervious made of concrete and asphalt, with solar reflectance values ranging between approximately 4% and 45%, which can reach peak summertime surface temperatures of 48°C-76°C.



(a) Hotspots



(b) Relationship with the blog area

Siqi, Jia, and Wang Yuhong. "Effects of land use and land cover pattern on urban temperature variations: A case study in Hong Kong." Urban Climate 34 (2020): 100693.

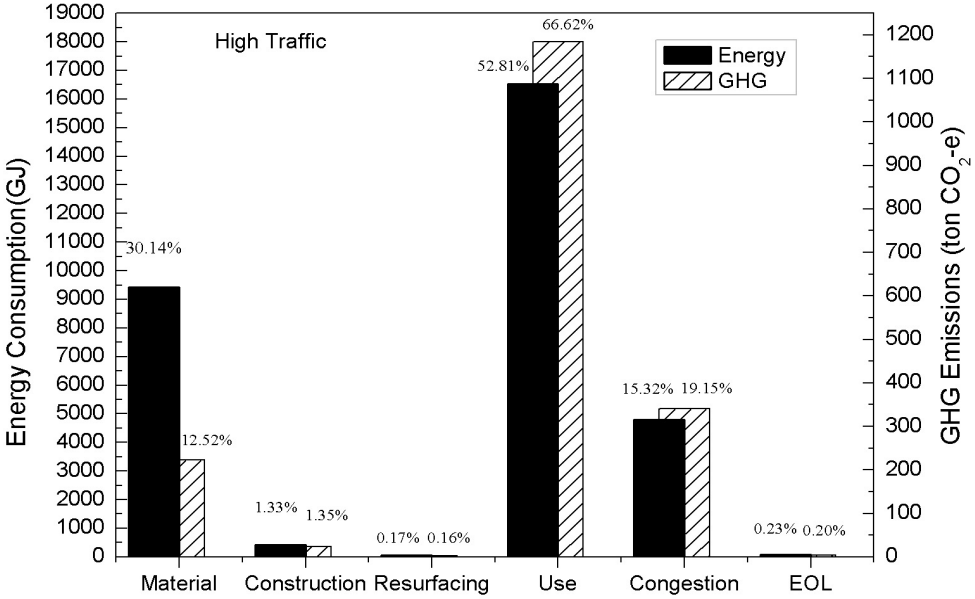
Problems of Current Urban Pavements

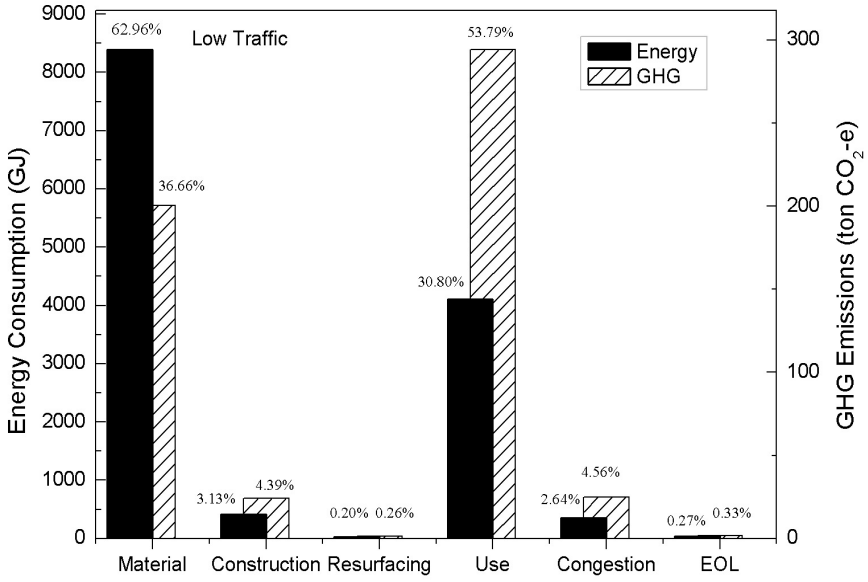
- "Smart mobility" is the first of six major development areas that have been identified for smart city, aiming to develop more efficient, convenient, and environmentally friendly transport systems through the adoption of innovative information and communication technologies (ICT).

Source: Hong Kong Innovation and Technology Bureau, 2017. Hong Kong Smart City Blueprint.
Joan Koka, Argonne National Laboratory, 2018. Demystifying the future of connected and autonomous vehicles. https://phys.org/news/2018-06-demystifying-future-autonomous-vehicles.html

Problems of Current Urban Pavements

- It is estimated that transport sector accounts for nearly 14% of global GHG emissions. Road transportation consumes a large quantity of fossil fuel, and a large portion is wasted due to road closures.





Source: Chong, D., & Wang, Y. (2017). Impacts of flexible pavement design and management decisions on life cycle energy consumption and carbon footprint. The International Journal of Life Cycle Assessment, 22(6), 952-971.

Our Solution

- Prefabricated Structures
- Surface-induced Smart Porous Pavement
- Surface Textures for Skid Resistance and Noise Abatement
- Energy Harvesting from Pavement Surface
- New Pavement Surface for Safety Improvement
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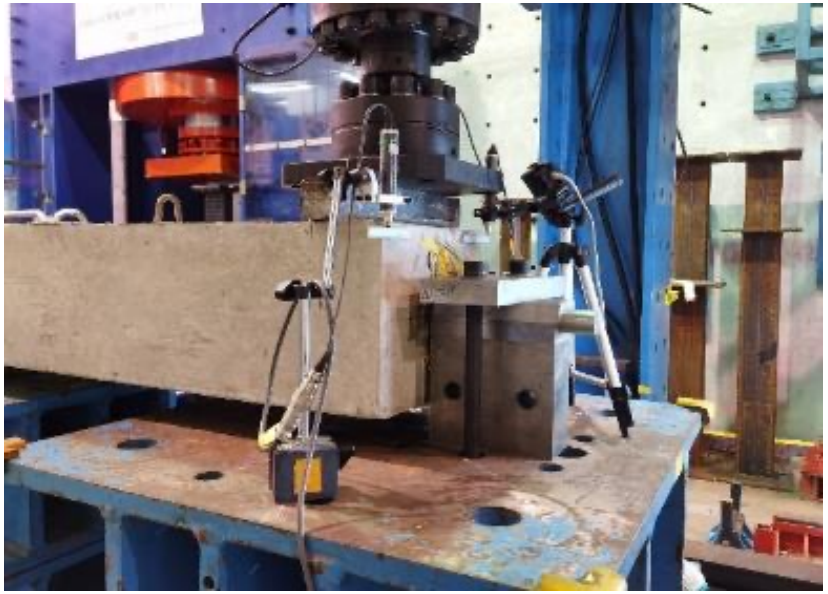
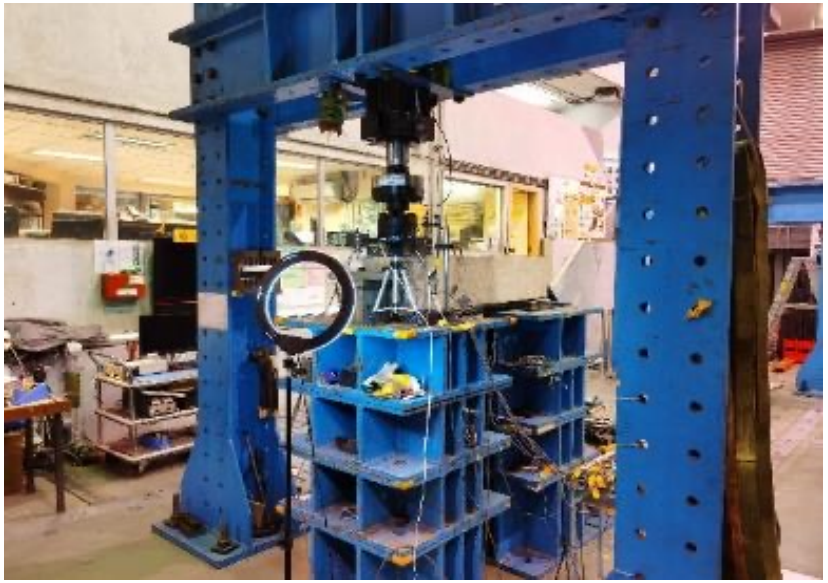
- **The key is to develop connectors between concrete slabs**
  - Easy installation
  - Easy uninstallation
  - Even distribution of loads
- Slab structure
  - Shape
  - Internal details
- Integration of weigh-in-motion (WIM) function

- **We have developed three connector systems.**

Test setup





Data measurement

Failure modes

Specimen type	Crack load (kN)	Peak load (kN)	Failure mode
32D	5.36	126	Horizontal cracks and shear cracks
32D4T	7.04	183	Shear cracks
32D4T10R	12.34	231.3	Shear cracks

Test figures

What is a sinkhole and what causes them? | London Evening Standard | Evening Standard
(https://www.standard.co.uk/news/world/what-sinkhole-causes-locations-a4448081.html)

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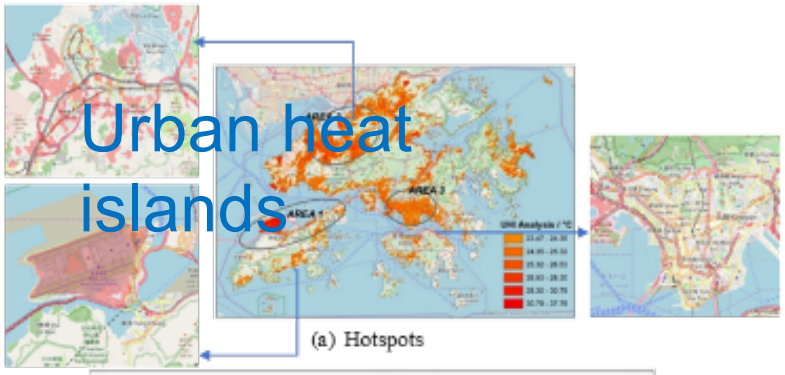
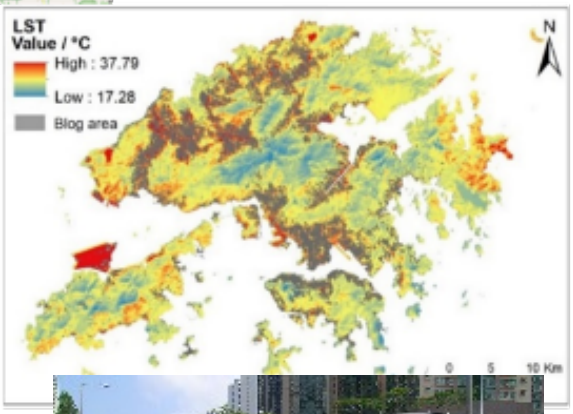
We buy water to irrigate plants

Stormwater runoff pollutes our rivers

http://xw.sinoins.com/2020-05/22/content_344964.htm

Urban heat islands





Deicing in winter time

Source: https://pprc.org/2015/p2-rapid/how-to-reduce-the-environmental-impact-of-deicing/

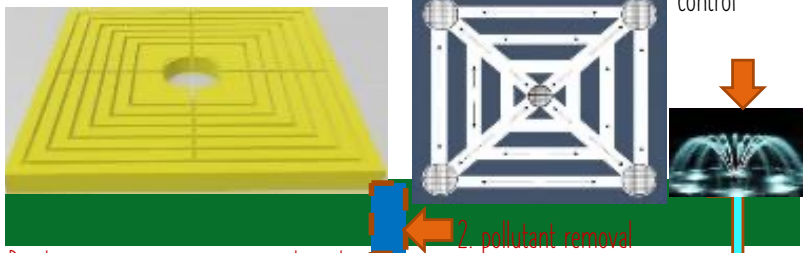
Dusts from road surface

Can we make a road that can:

- ✓ Reduce flooding?
- ✓ Remove pollutants from runoff?
- ✓ Harvest rainwater?
- ✓ Make road cooler in summer?
- ✓ Deice itself in winter?
- ✓ Clean itself?

Yes, we can!

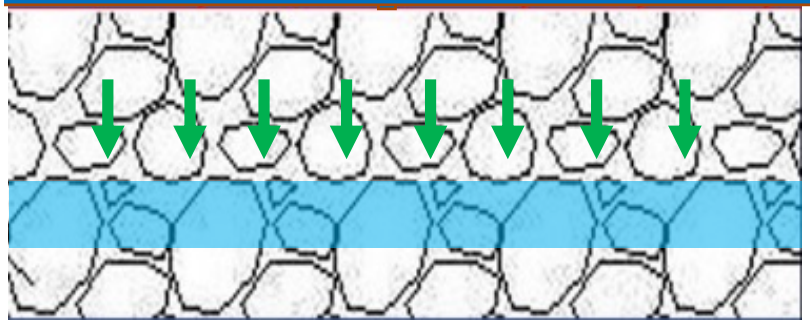
1. Surfaced-induced porous pavement, made with the assistance of 3D printing (patent pending)

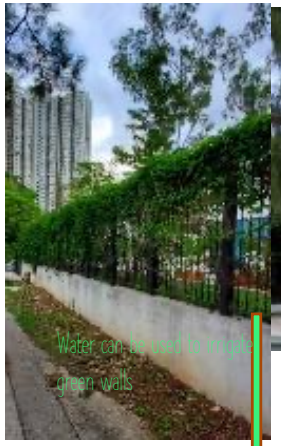


3. Deicing /cooling/dust control

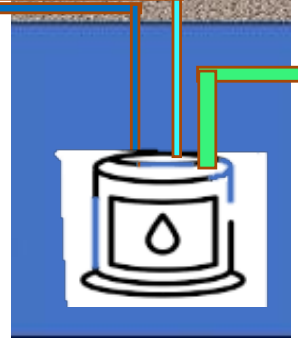
2. pollutant removal

Road is as strong as conventional road

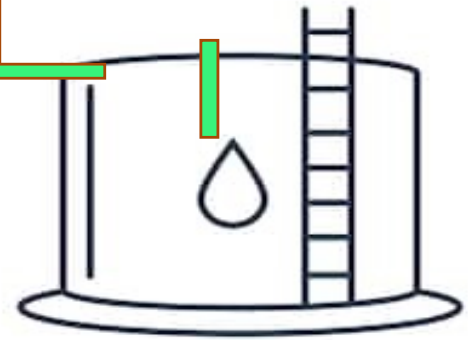




The secondary tank can be placed under a large space such as roundabout



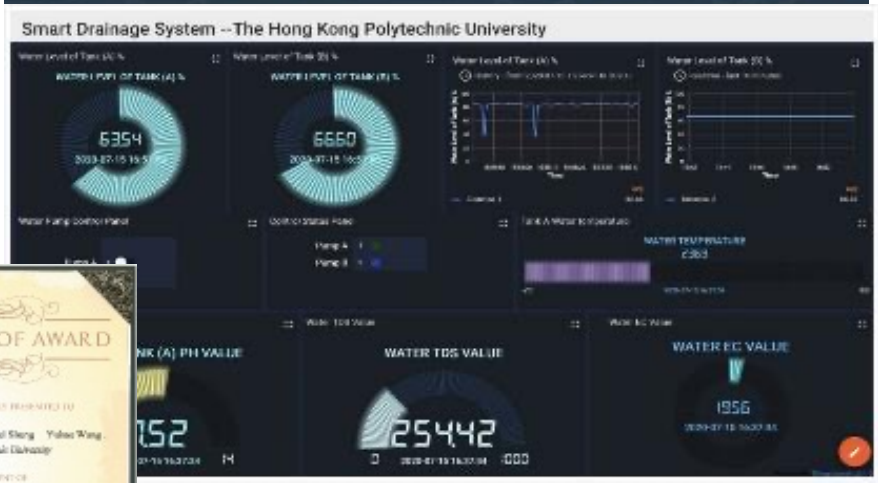
4. Primary storage tank and pump



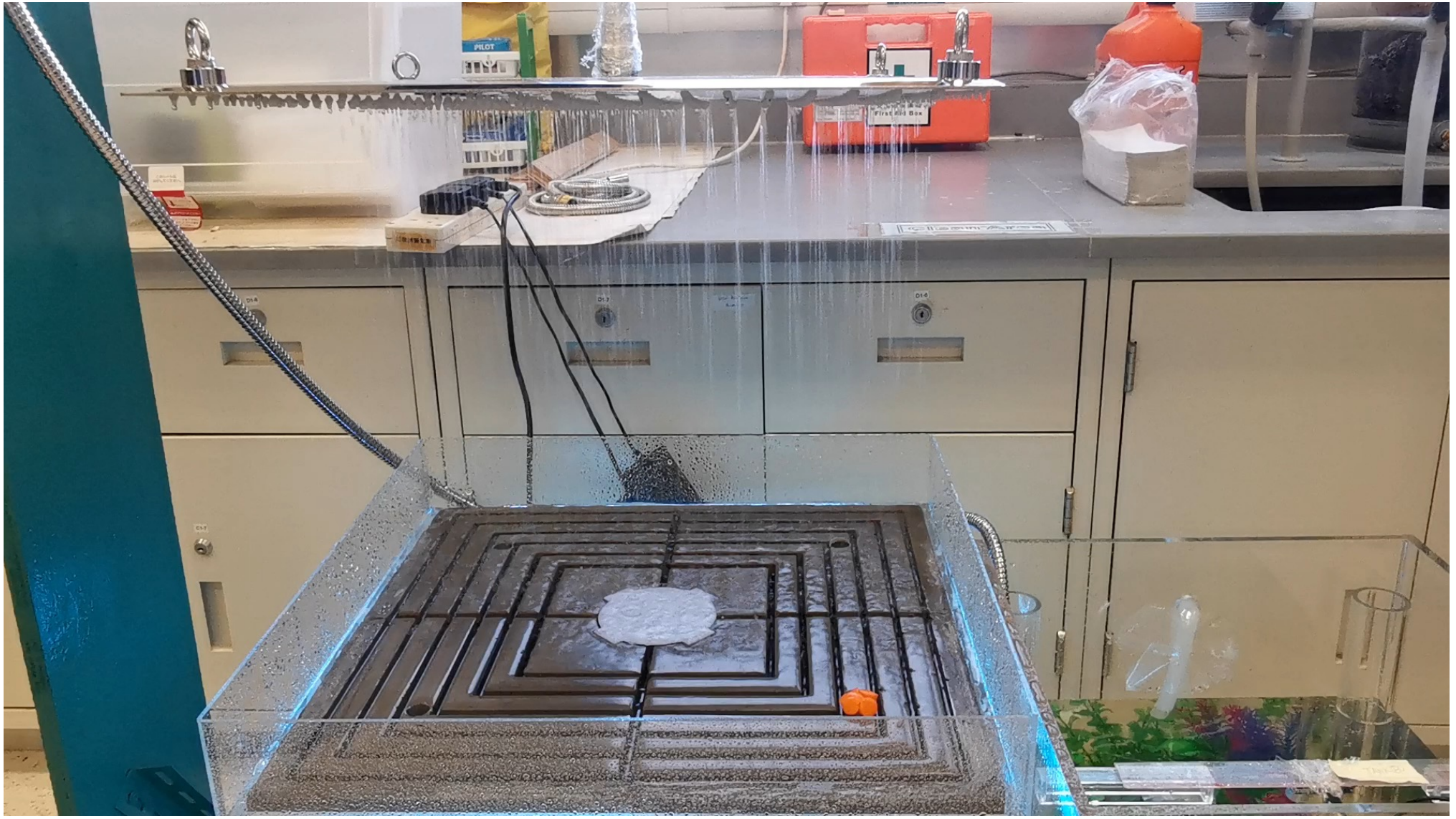
5. Secondary storage tank and pump

IoT Sensors and Microcontrollers

6. Cloud platform for monitoring and control



Integrated Porous Pavement System



Integrated Porous Pavement System

Site Trial

EM/P20604CN00

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发文日：

2019 年 03 月 26 日

申请号或专利号：**201910233496.X**　　发文序号：**2019032602002240**

专 利 申 请 受 理 通 知 书

根据专利法第 28 条及其实施细则第 38 条、第 39 条的规定，申请人提出的专利申请已由国家知识产权局受理。现将确定的申请号、申请日、申请人和发明创造名称通知如下：

申请号：201910233496.X
申请日：2019 年 03 月 26 日
申请人：香港理工大学
发明创造名称：一种表面导向型透水铺装结构

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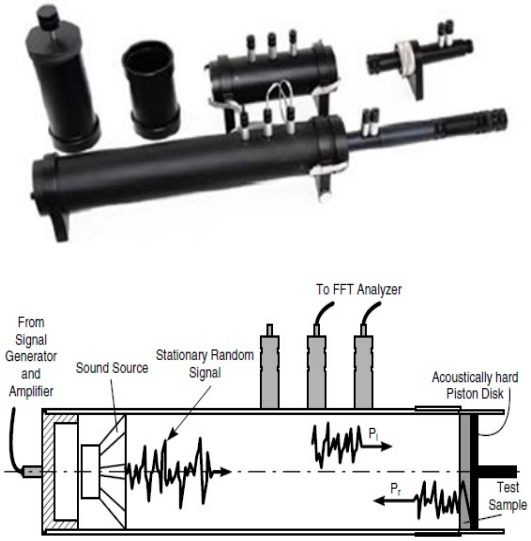
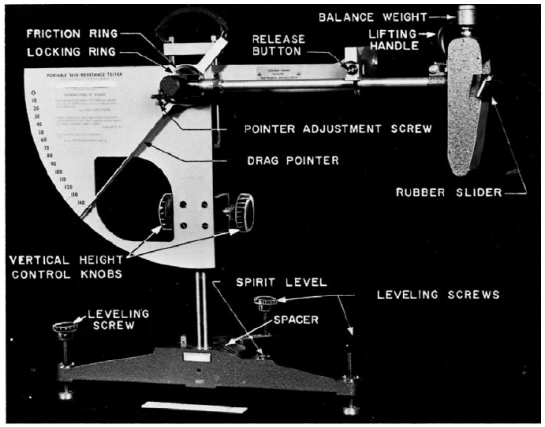
Laboratory test



Noise test
Two Microphone Impedance Measurement Tube

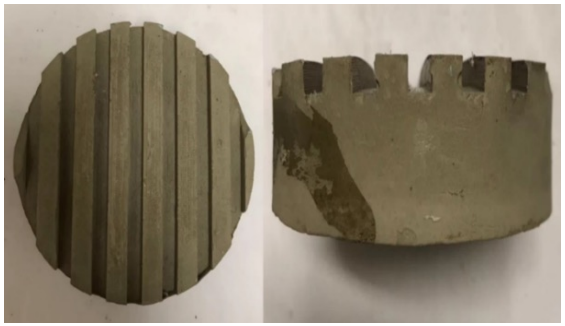


Skid resistance test
British pendulum skid resistance tester

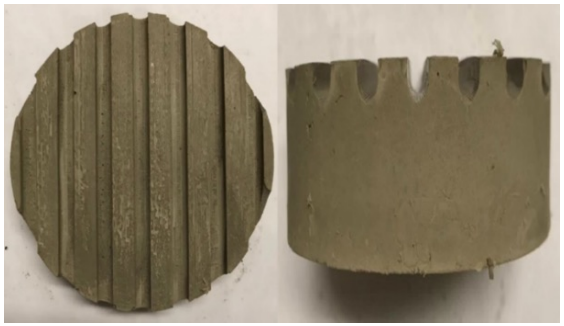
Pre-fabricated Surface Texture for Better Noise Performance and Skid Resistance

Noise test

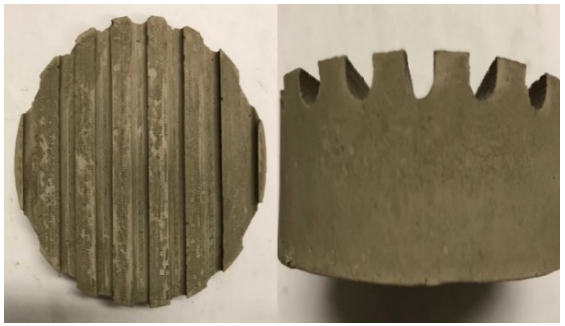
(1) Sample preparation



Rectangular texture

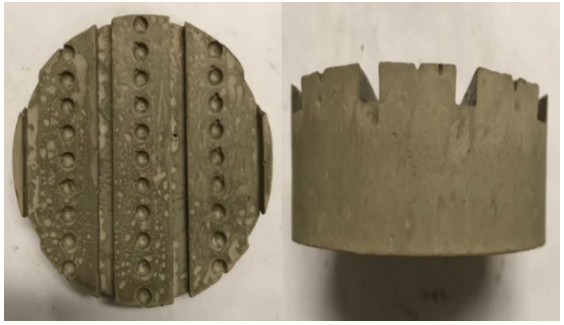


Semicircle texture



Arc-shaped texture

Rectangular texture with cylindrical hole



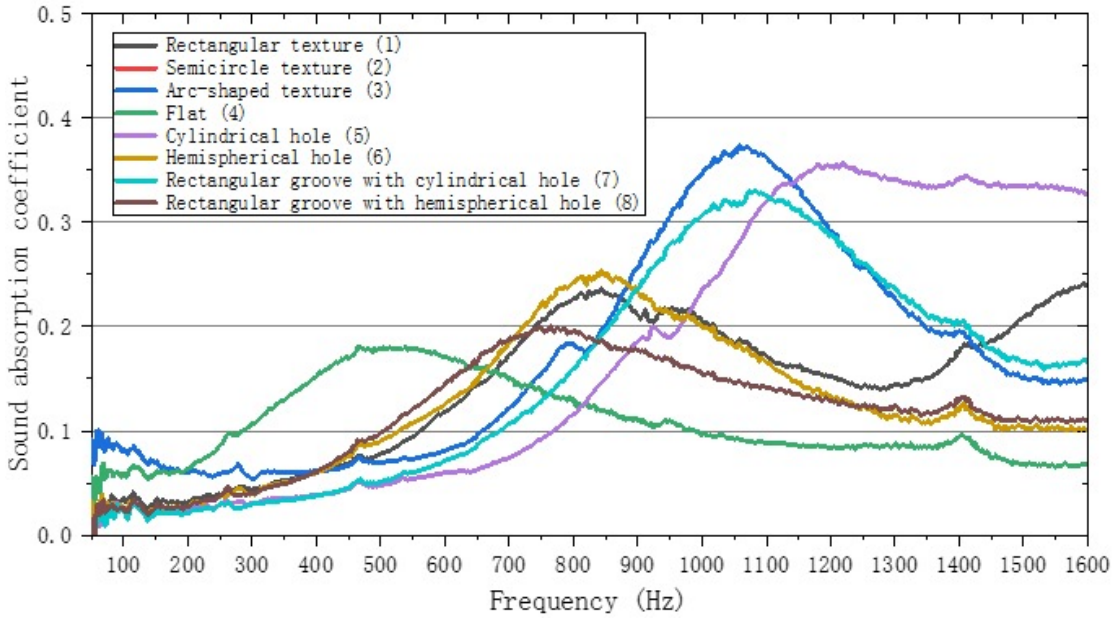
Rectangular texture with hemispherical hole

Hemispherical hole

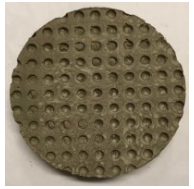
Cylindrical hole

Pre-fabricated Surface Texture for Better Noise Performance and Skid Resistance

(2) Test results



Arc-shaped texture



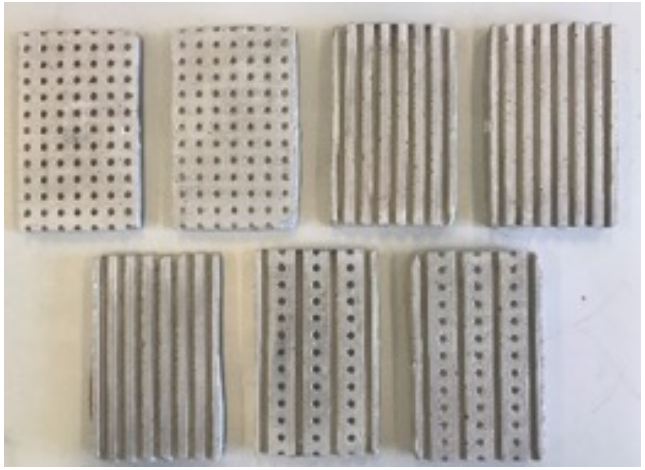
Cylindrical hole

R & C

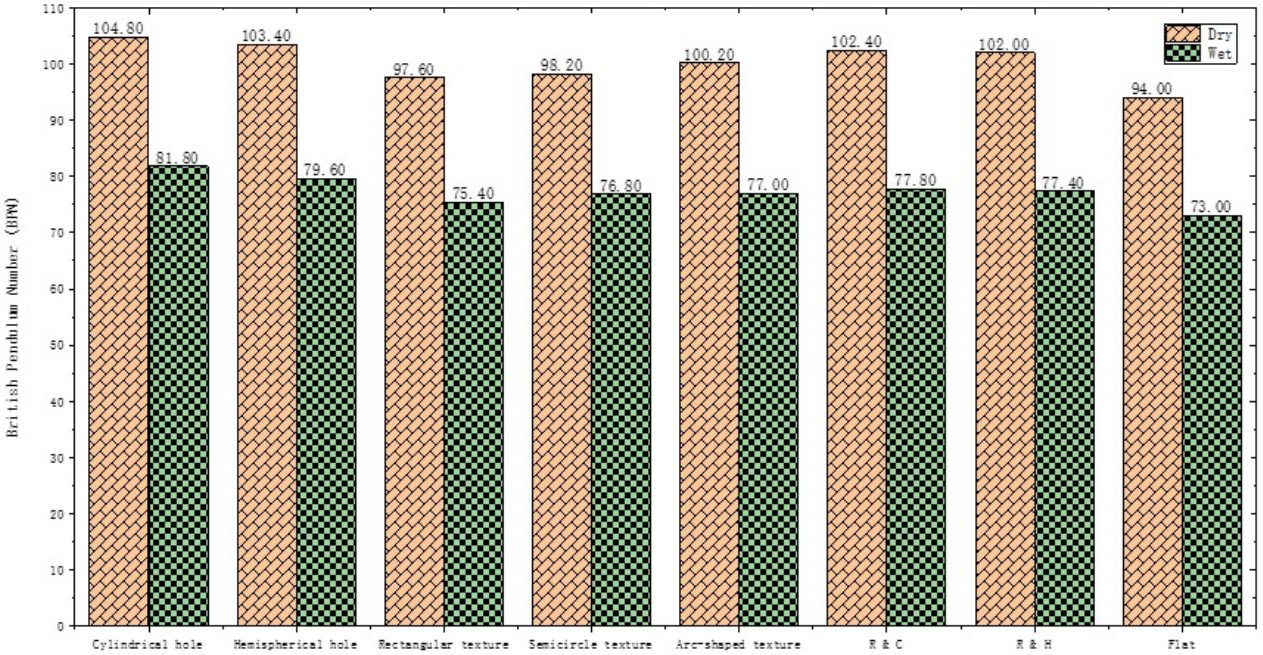
Results of the sound absorption coefficient of all textures

Skid resistance test

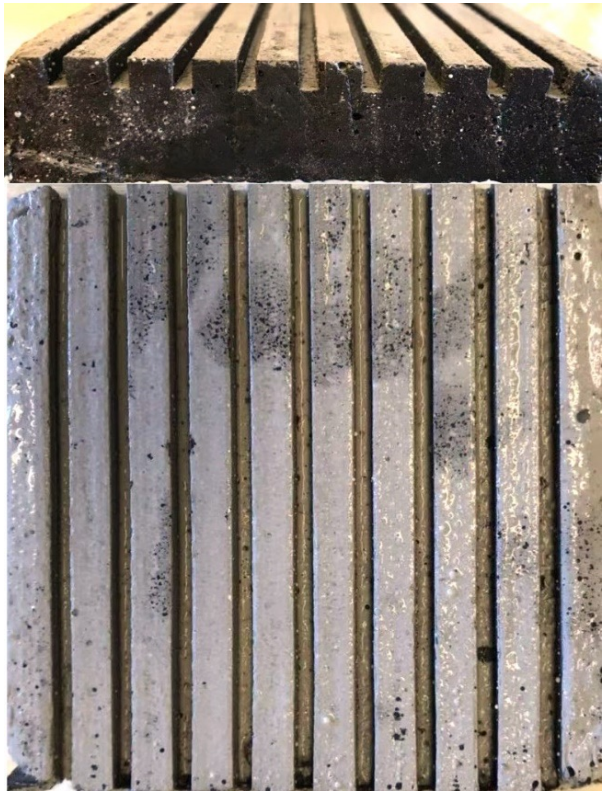
(1) Sample preparation



(2) Test results



Pre-fabricated Surface Texture for Better Noise Performance and Skid Resistance



Rectangular

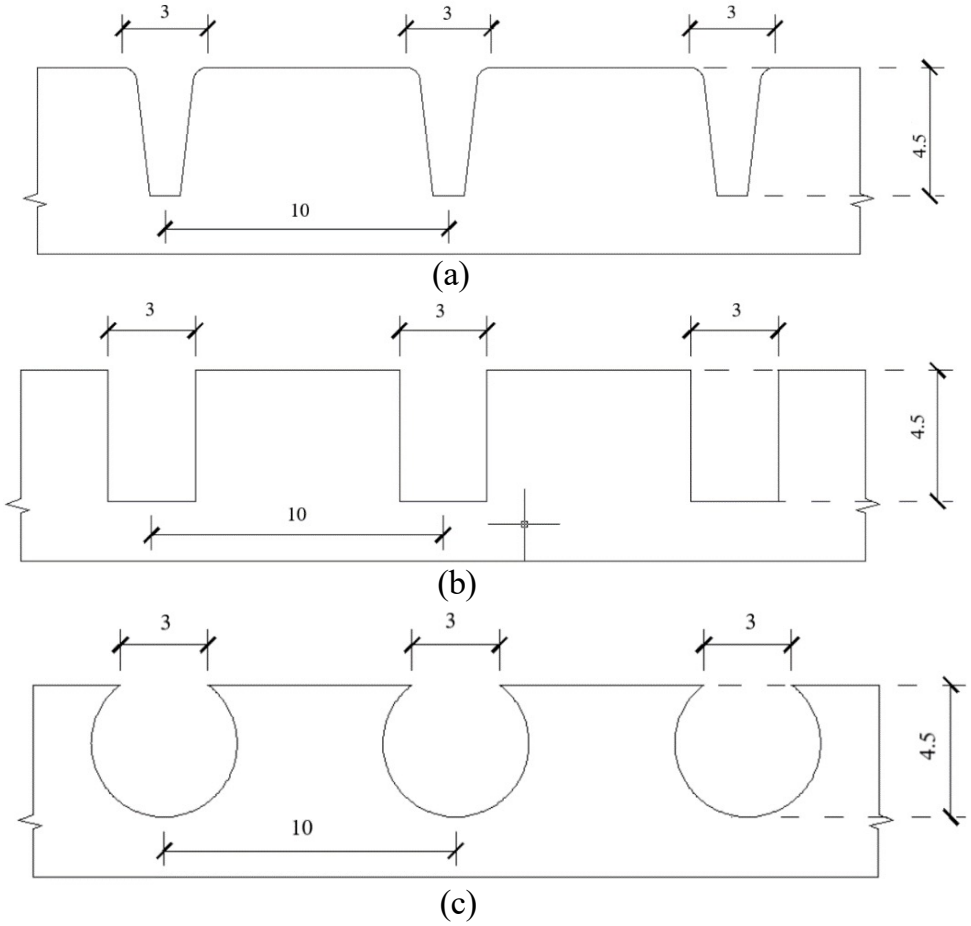
Arc-shaped

Trapezoid

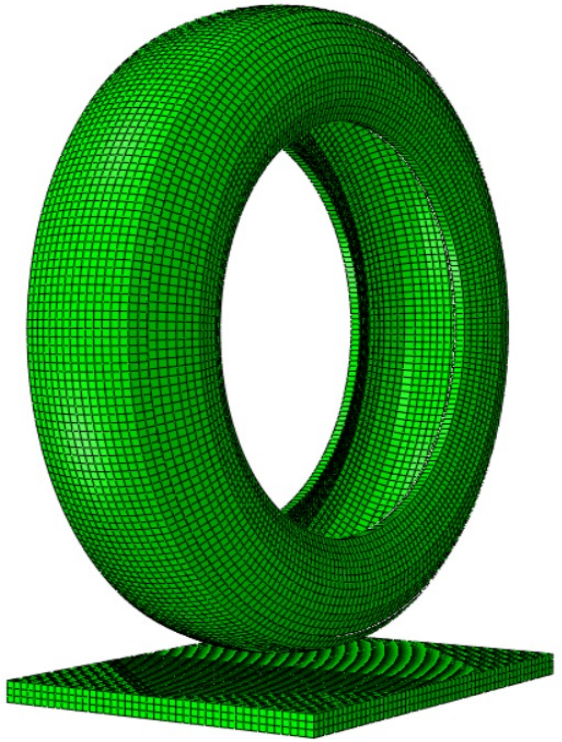
Pavement Surface Texture Created with the Assistance of 3D Printing Technology

Pre-fabricated Surface Texture for Better Mechanical Properties

(1) Simulation of the tire-pavement texture interaction



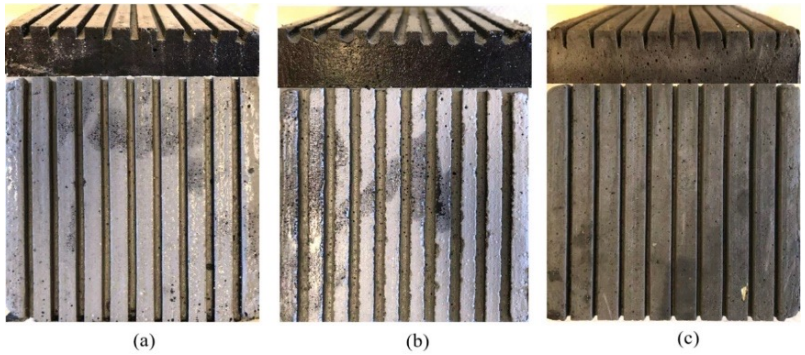
Three types of pavement texture, designed and subsequently produced by 3D printing technology: (a) rounded trapezoid texture, (b) rectangular texture, (c) arc-shaped texture



Tire-pavement interaction model

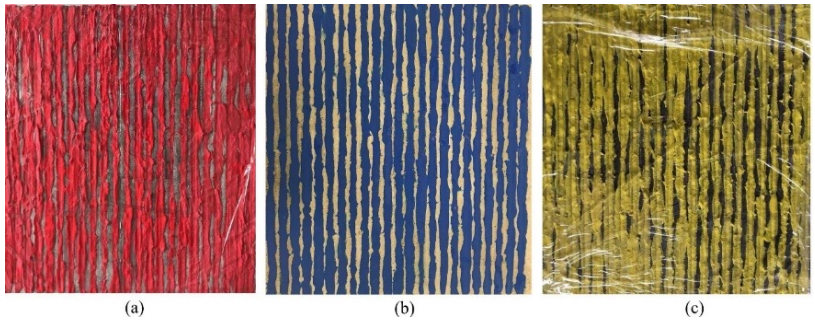
Pre-fabricated Surface Texture for Better Mechanical Properties

(2) The experiment and validation of the tire-pavement texture model

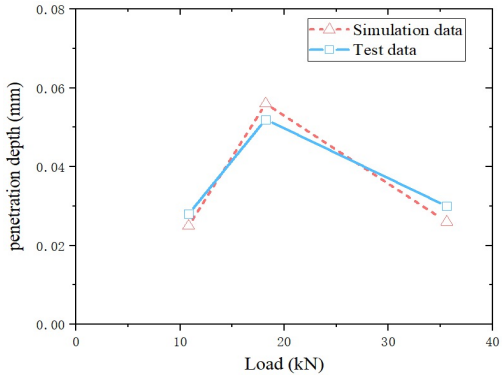


Specimens with (a) rectangular texture, (b) arc-shaped texture, and (c) rounded trapezoidal texture

Loading test (a) 10.8 kN, (b) 18.2 kN, (c) 35.6 kN

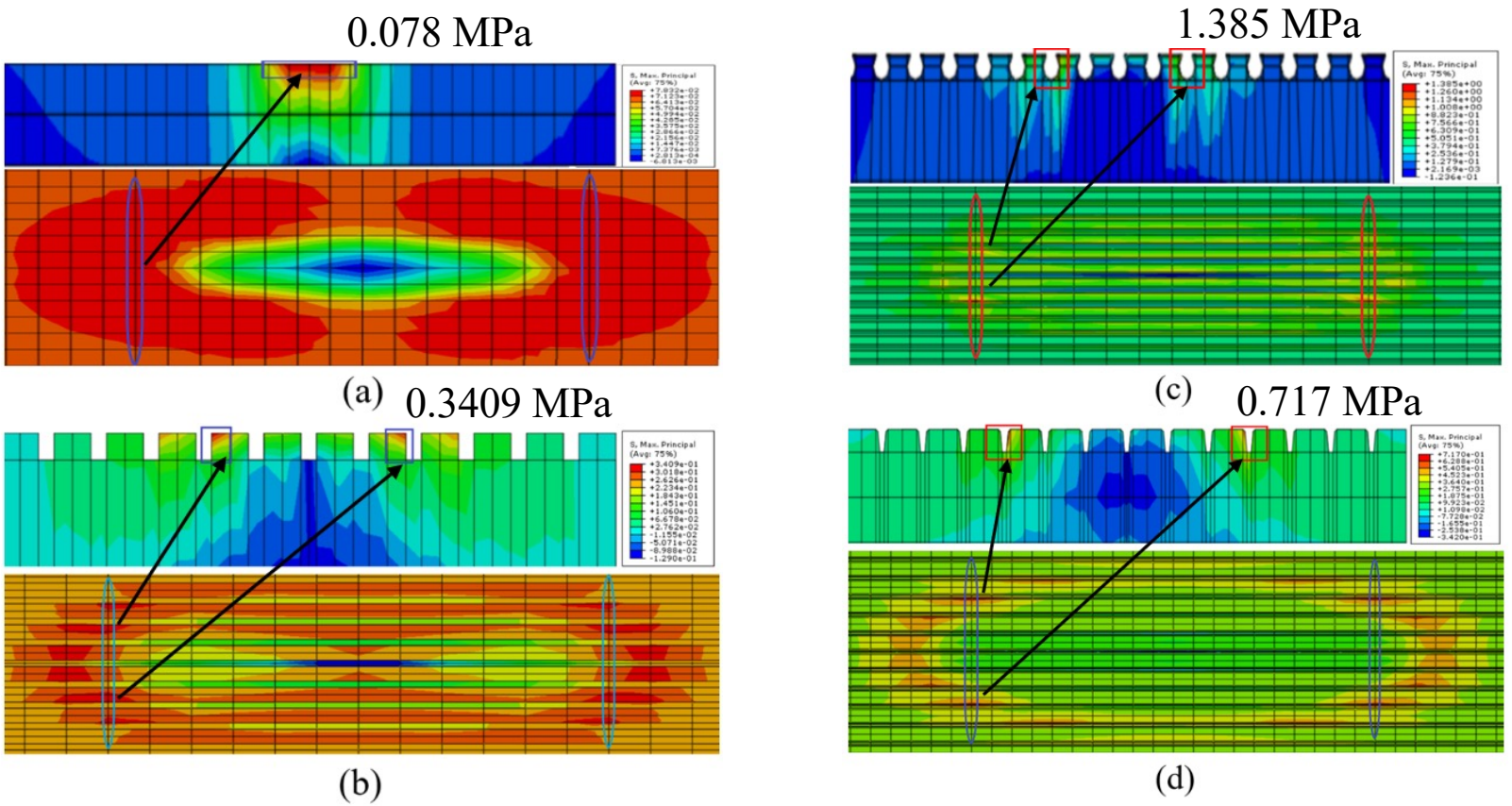


Specimens filled with silly putty



Comparison of the penetration depth obtained from modeling and test

(4) Analysis of the maximum/minimum principal stresses (S_{max}/S_{min}) of different types of textures



The maximum principal stress of (a) the rectangular texture, (b) the arc-shaped texture, (c) the rounded trapezoidal texture

- Content
  - Introduction
  - Prefabricated Structures
  - Surface-induced Smart Porous Pavement
  - Surface Textures for Skid Resistance and Noise Abatement
  - Energy Harvesting from Pavement Surface
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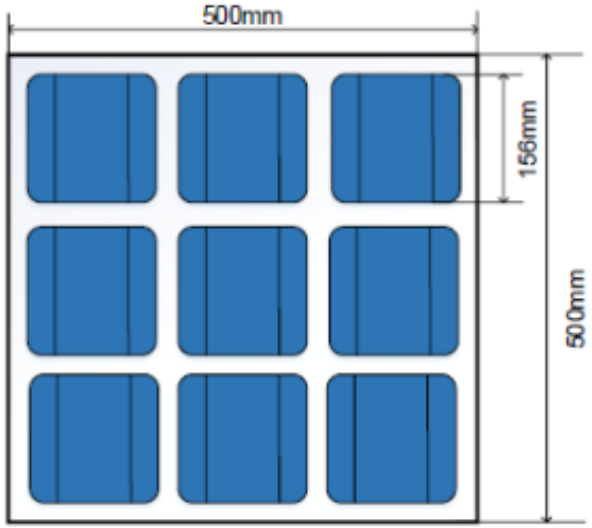
  - Pavement-based Vehicle Position System
  - Automatic Prefabrication and Construction
  - Conclusion and Future Perspectives

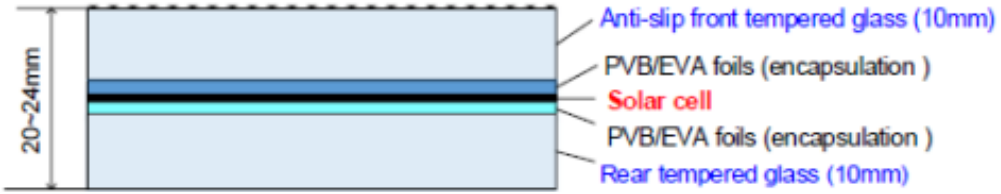
State of the Art

- Photovoltaic road

Incorporation of Solar Panels in Pavements



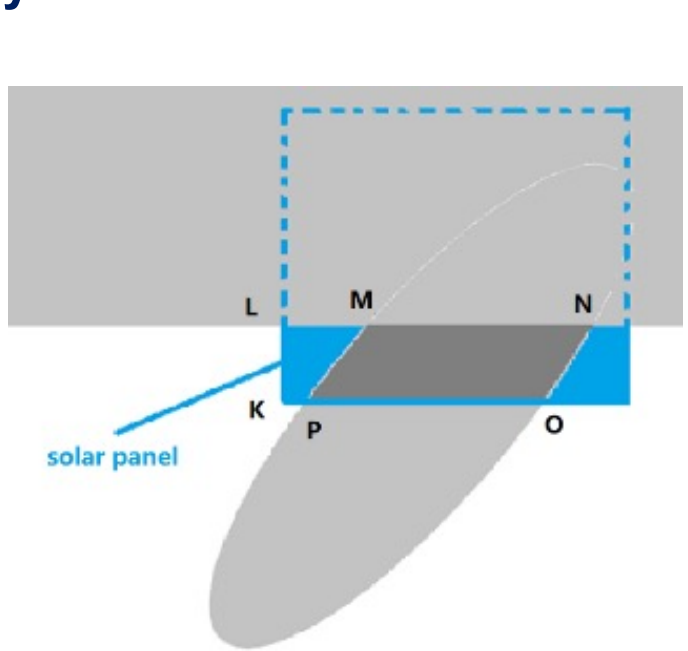
- Size: 500×500mm
- Thickness: ~20mm
- 9 monocrystalline silicon solar cells connected in series or parallel
- Expected power: **30-40Wp**
- Expected efficiency: **15%**
- Annual output: **100kWh/m2**

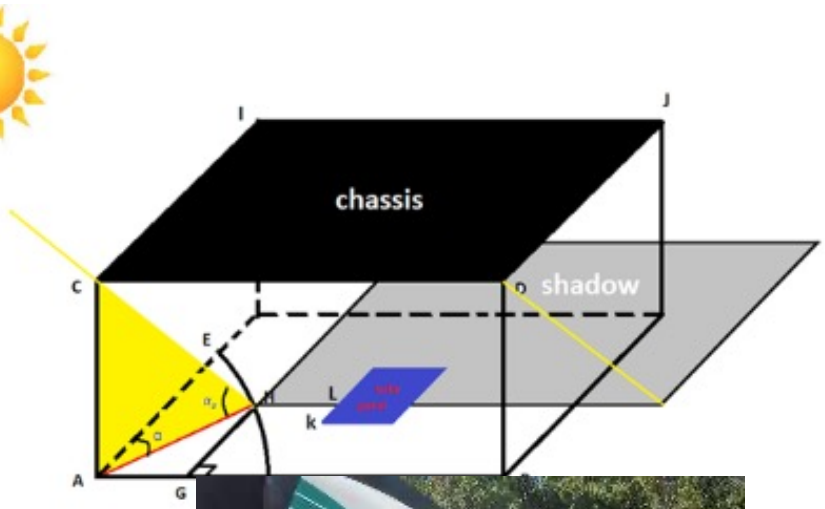


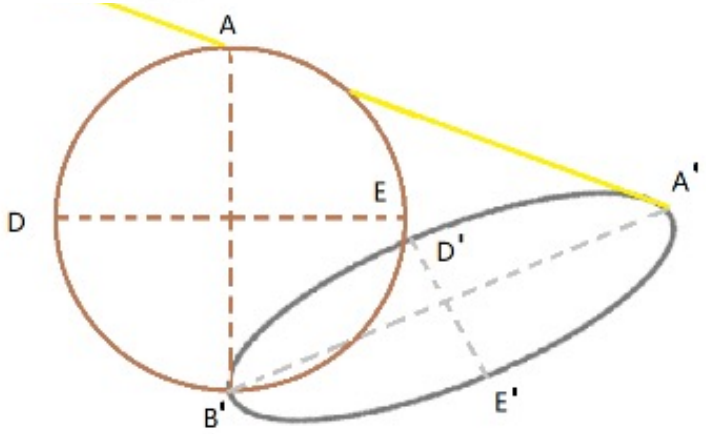
Incorporation of Solar Panels in Pavements

Incorporation of Solar Panels in Pavements

Energy Generation Calculation

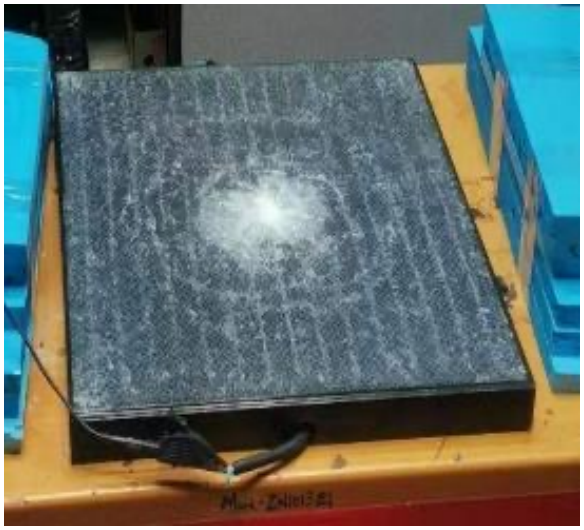


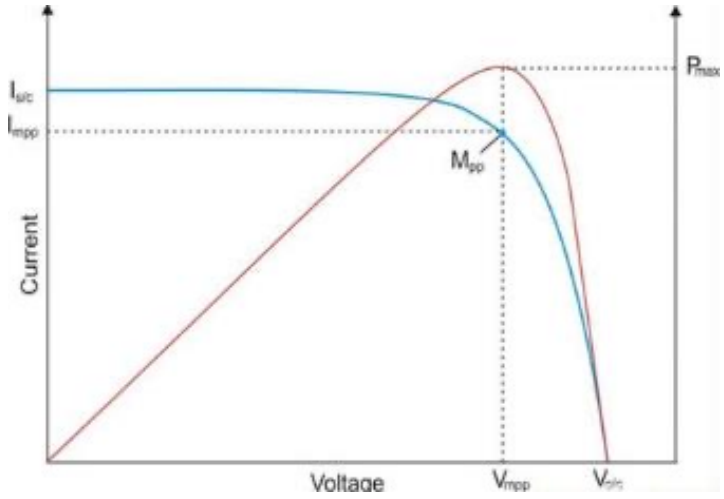




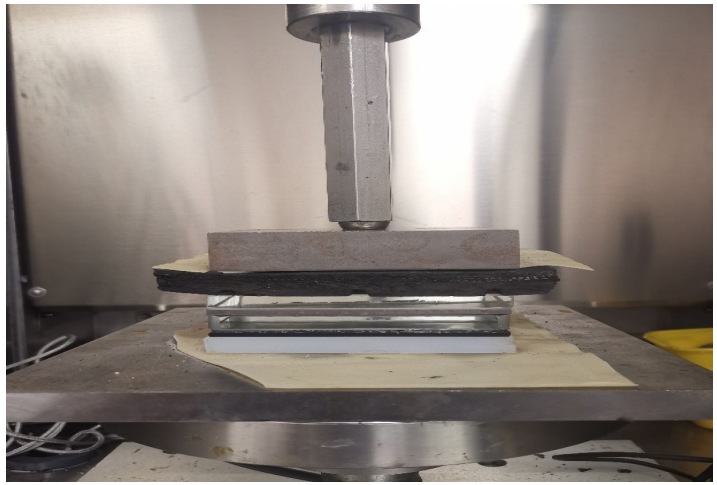
Incorporation of Solar Panels in Pavements

Mechanical tests of solar panels for road use

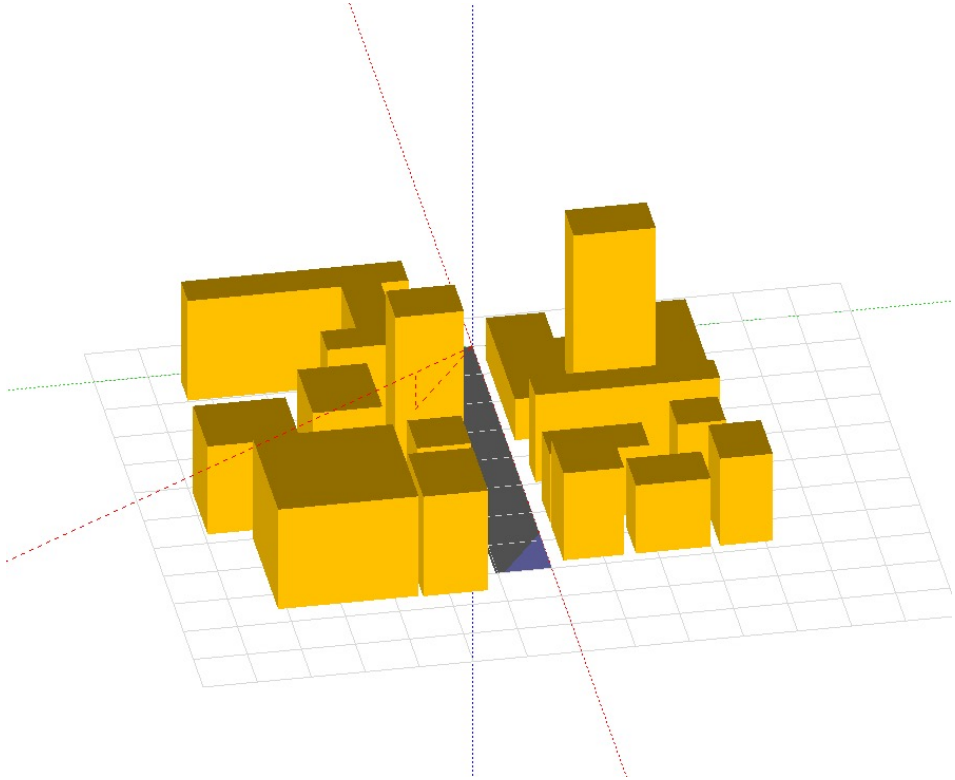




Tests of the durability and performance of solar road panel

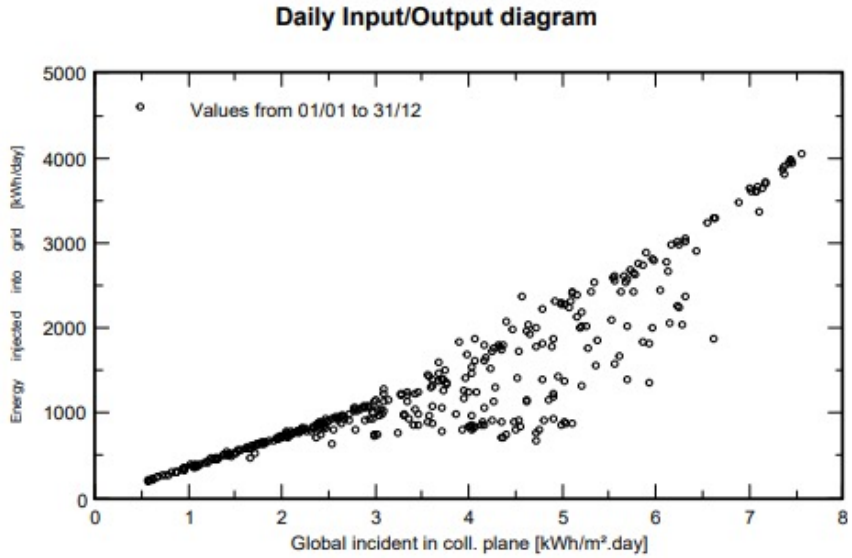


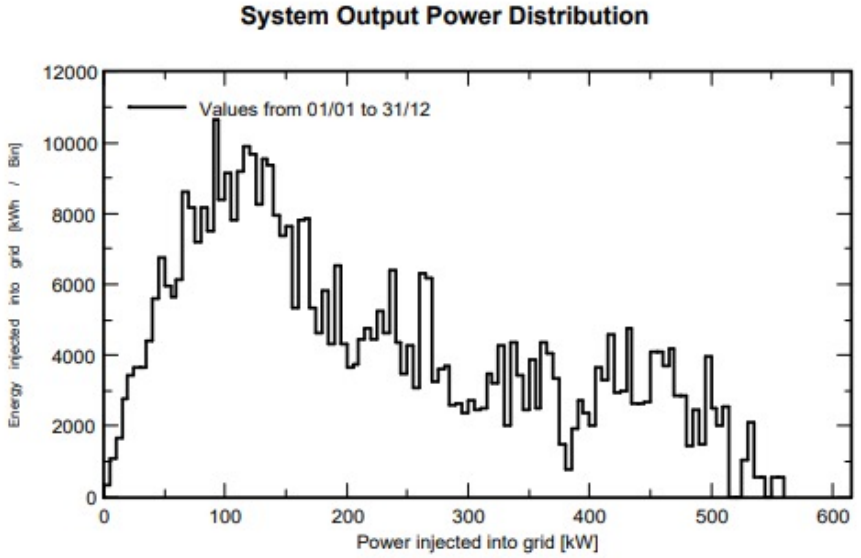
Photoelectric system production simulation



Main results

System Production	**475** MWh/yr	Normalized prod.	**1.63** kWh/kWp/day
Specific prod.	**594** kWh/kWp/yr	Array losses	**1.89** kWh/kWp/day
Performance Ratio	**0.455**	System losses	**0.06** kWh/kWp/day





- Content
  - Introduction
  - Prefabricated Structures
  - Surface-induced Smart Porous Pavement
  - Surface Textures for Skid Resistance and Noise Abatement
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Safety Improvements through Pavements: Work Zone Safety

- Fatality risks in road work zone are twice as high compared to non-work zone

- Work zone fatal crashes and fatalities in U.S.

	Fatal Crashes	Fatalities
2018	672	755
2017	720	809
2016	688	782

Road maintenance workers working in the zone

- Work zone accidents at night are five times more than those during the day.

Safety Improvements through Pavements

Design of experiment :

Two experimental scenes

Design of experiment :

Driving simulator

Experiment process: (a) participant wearing eye tracker and (b) experimental scene.

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  - Introduction
  - Prefabricated Structures
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Self-driving Cars (Autonomous Vehicles)

For example, WeRide has raised more than $500 million since for self-driving cars.

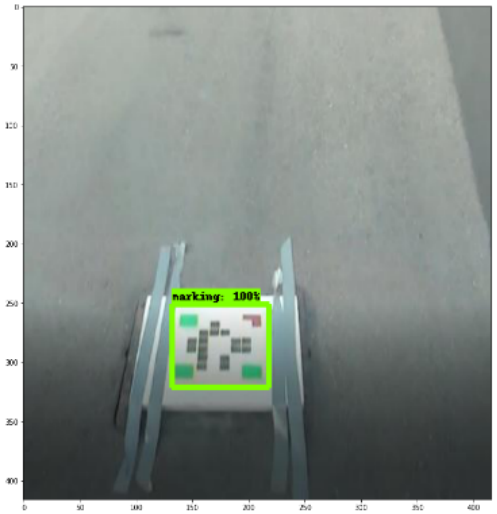
https://www.therobotreport.com/chinas-weride-raises-another-110m-for-autonomous-vehicles/

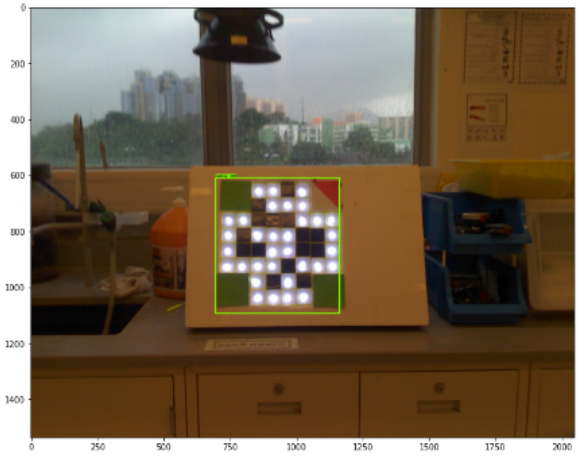
Accurate Positioning from Road Pavement Surface

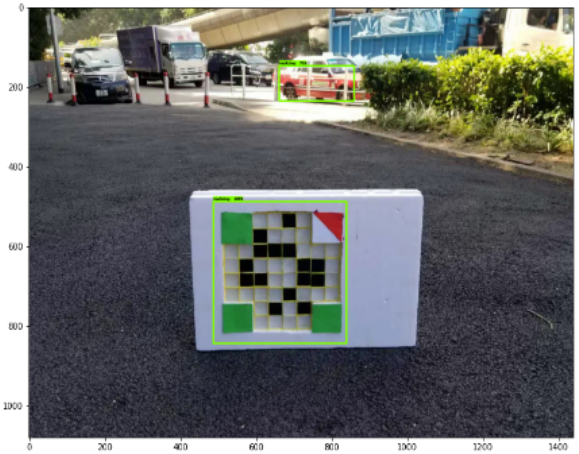
Challenges in accurate positioning

- ✓ **New methods are needed for positioning from pavements in addition to satellite positioning system.**

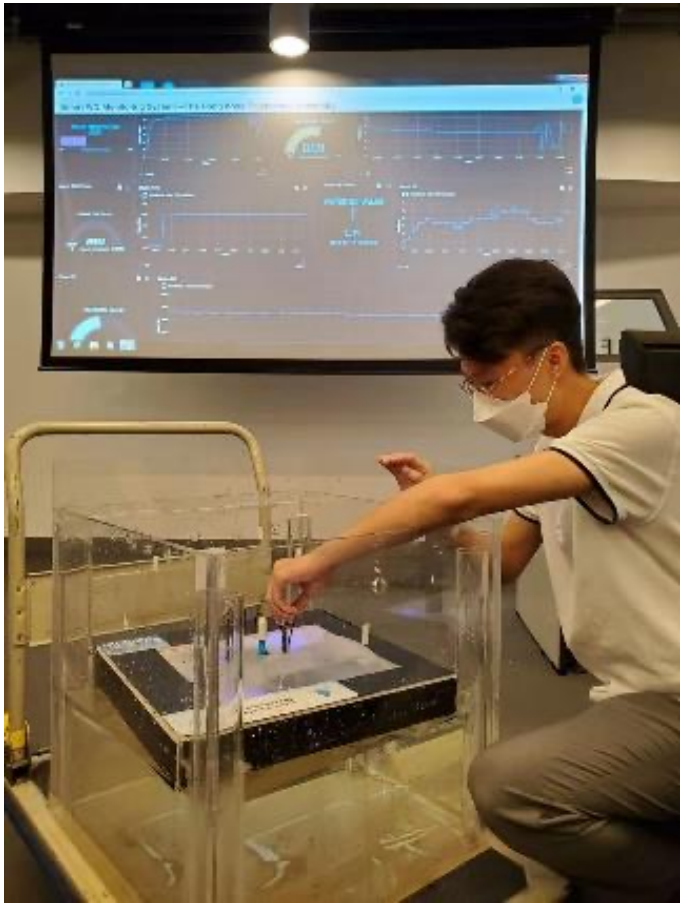
Pavement-based Vehicle Position System







Pavement-based Vehicle Position System



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发文日：

2021 年 01 月 19 日

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专 利 申 请 受 理 通 知 书

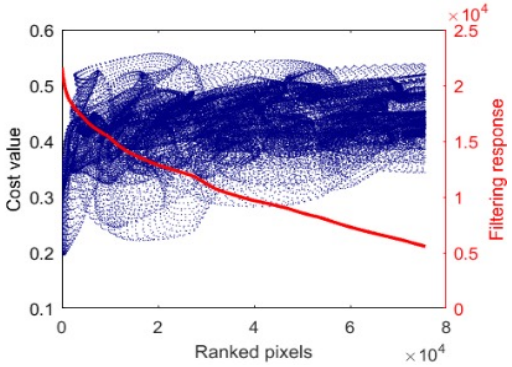
根据专利法第 28 条及其实施细则第 38 条、第 39 条的规定，申请人提出的专利申请已由国家知识产权局受理。现将确定的申请号、申请日、申请人和发明创造名称通知如下：

申请号：202110064293.X

申请日：2021 年 01 月 18 日

申请人：香港理工大学

发明创造名称：一种为无人驾驶车辆服务的道路定位标识



The Hong Kong Polytechnic University 香港理工大學

- Content
  - Introduction
  - Prefabricated Structures
  - Surface-induced Smart Porous Pavement
  - Surface Textures for Skid Resistance and Noise Abatement
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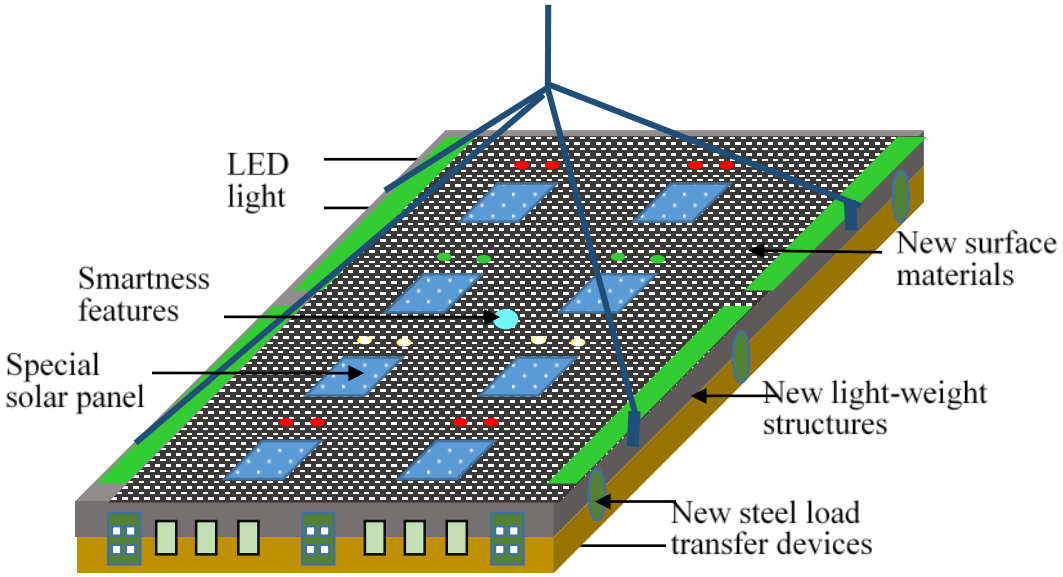
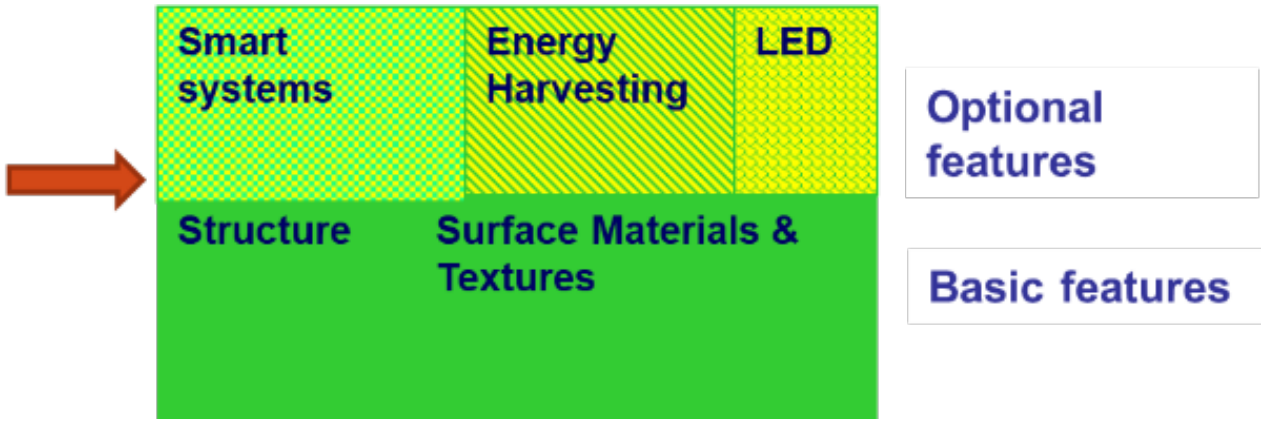
Final Product

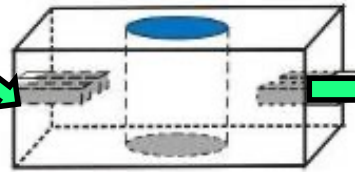


A series of products will be developed to strike a balance between cost and needs.



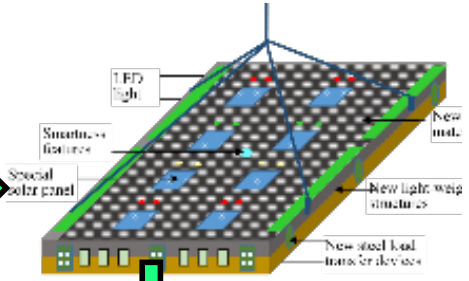
Integration and Implementation

- **Building Information Modeling (BIM)** will be used in design, fabrication, and life-cycle asset management.

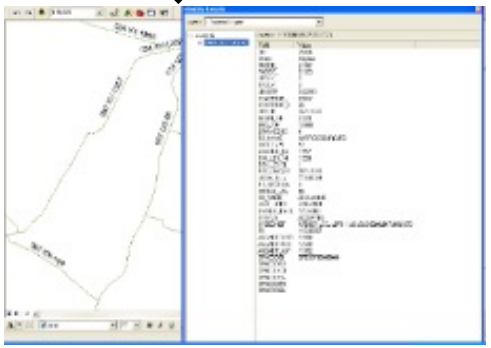


BIM

Fabrication



Construction



Asset
Management

Conclusion and Future Perspectives

Concrete structure offers endless opportunities for future smart roads.

Conclusion and Future Perspectives

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