Sustainable High Density Cities: Empowering Practitioners with Digital Technologies

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Background

Over the course of history, the density of human settlements resembles a hockey stick graphic: A hunter-gatherer society rarely exceeded 1 person per 25 km2 due to limits in primary productivity and ecological resources, while farmlands average 100 times that [1], thanks to the increased carrying capacity of cultivated land. The Industrial and information revolution made contemporary cities denser, larger, and have led to growth at an unprecedented speed: the top 101 mega cities are home to 11% of the world's population, and the percentage is expected to reach 23% by the end of this century [2]. Our civilization appears on-track to turn Earth into an urban planet [3].

Hong Kong is an exemplar of high density cities and a favored case study. The city's 7 million+ people occupy a built-up area of 280 km2, with an average population density of 27,330 persons per km2 [4]. New York City can match that if all its population is squeezed into Queens, one of its five boroughs. Close proximity of people fosters exchange of goods, services, information and ideas, making cities efficient, vibrant, innovative, rich, and healthy [5,6]. The claim is largely supported by statistics: Hong Kong ranks consistently high globally in indictors ranging from economic competitiveness to life expectancy. The city operates a world-class public transit system, its public housing system accommodates nearly half of its population and receives wide citations [7,8], and so on.

Packing a large population into a small area can however bring unprecedented risks to human health and quality of life. Hong Kong and other dense cities have been combatting weather extremes, environmental pollutions, and outbreaks of infectious disease for decades. The concrete jungle of buildings can stagnate air movement and trap exhaust heat, air pollutants, and pathogens inside street canyons. The recordings for urban heat island effect (UHI) in Hong Kong reach 4-6 C above those of the surroundings [9], and excessive heat is linked to higher population mortalities and morbidities globally [10][11]. Hong Kong's on-street

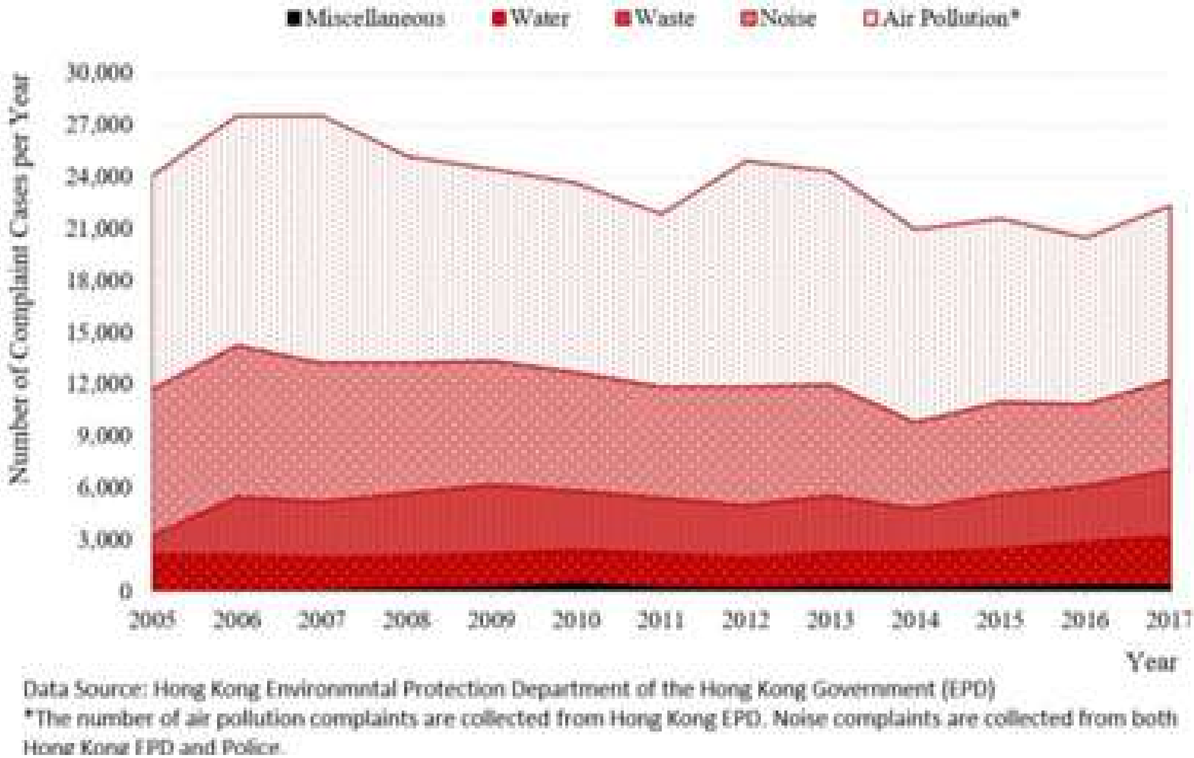

Fig. 1 Environment pollution of the air, noise, and waste are top concerns expressed by Hong Kong's residents

PM2.5 exceeds 40 μg/m3 [12], above the WHO threshold of 25 μg/m3, and the majority of air pollutants are contributed by local sources, i.e. motor vehicles, marine vessels and power plants [13]. Air pollution, environmental noise, waste are among the top three source of complaints received by Hong Kong's Environmental Protection Department in recent years(Fig. 1). The frequent flow of people and materials, i.e. transit ridership, banknotes, makes a high density city particularly vulnerable to infectious diseases: SARS, MERS, influenza, and the recent outbreak of the coronavirus.

Hong Kong resorts to a combination of regulations, incentive schemes and guidelines to protect wind, light, view, and other "public goods". Most are voluntary, non-binding instruments lead by the public sector and intended to transform market behaviors. Examples include the Air Ventilation Assessment (AVA), a regulatory procedure for major development and redevelopment projects aimed at enhancing air ventilation [14], The Sustainable Building Design Guidelines (SBD) and Hong Kong BEAM Plus Assessment (BEAM Plus) [15] are non-statutory, incentive-based standards intended to trans-

Fig. 2 (left) A bird's eye view of the Upper Ngau Tau Kok Estate redevelopment project. (right) physical model with the design concept of introducing wind while fencing out traffic noise. Source: Hong Kong Housing Authority [17]s

form design and development practices, and the HKGBC Guidebook on Urban Microclimate Study is a voluntary guideline that aims to empower professionals and to raise the awareness of the general public [16]. Pilot projects have been implemented by the public sector. Examples include the award-winning Upper Ngau Tau Kok Estate Phases 2 and 3, a purposefully designed housing estate to facilitate breeze, light, view, and comfort (Fig. 2). The outcomes are improved thermal comfort and overall satisfaction in the neighborhood [17]

Despite forward-looking policy agendas and innovative projects spearheaded by the public sector, a large proportion of urban planning and design practices are not responding. Much of the policy initiatives are yet to trickle down to the private sector. Take AVA for instance, a total of 157 projects have been registered at the Hong Kong Planning Department's AVA database since the inaction of policy in 2005. 133 projects, or 84% of the total, were conducted by the government itself. The total number of AVA registered projects account for less than 1% of total floor area during the same period [18]. A mere 8% of Hong Kong's total energy inputs are from non-fossil fuel sources, largely nuclear power from mainland China. Locally produced non-nuclear renewable energy account for 0.5% of the total energy input (Fig. 3). Business as usual is no longer an option, but the industry needs new thinking and tools in order to drive bottom-up innovations.

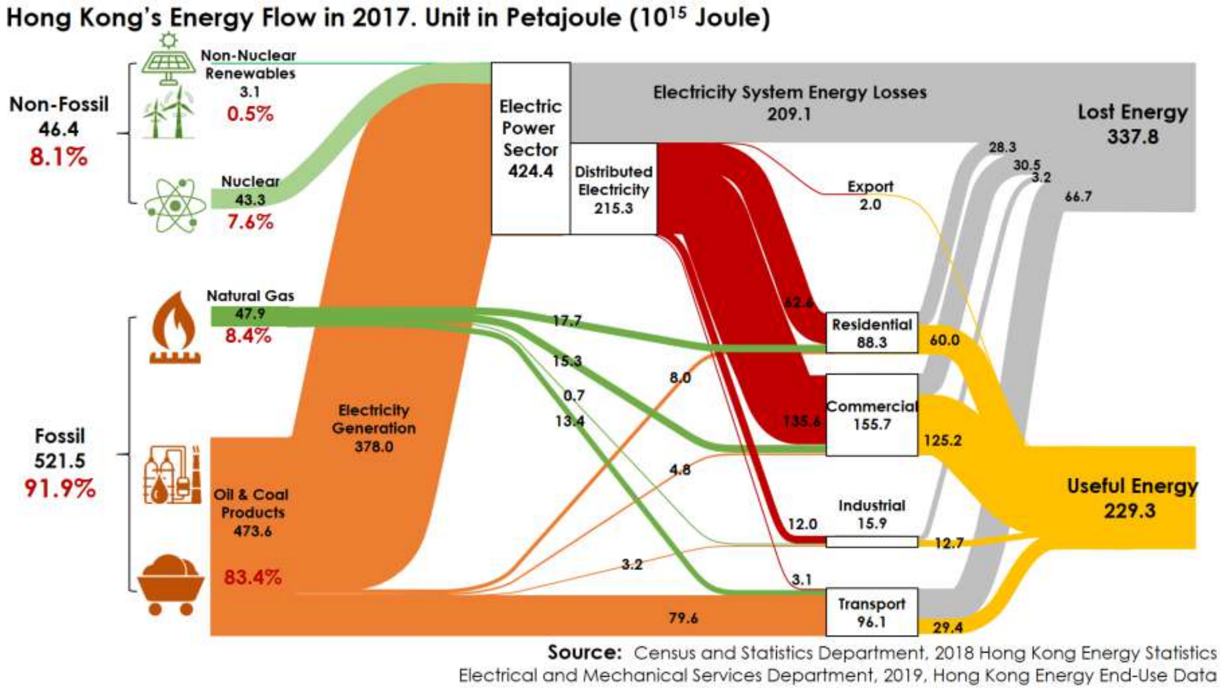

Fig. 3 Hong Kong's energy flow in 2017, by Jianxiang Huang, Chenxiao Li

The Sustainable High Density Cities Lab (SHDC) was established as a response to challenges that arise from the environmental risks of a high density city. As a multi-disciplinary research establishment within the HKUrban Lab in the Faculty of Architecture at the University of Hong Kong, SHDC is dedicated to research in multi-scale environmental modelling and built-environmental sciences that advance sustainable planning and design practices. Multi-scale means building interiors, single buildings, clusters of buildings, spaces between buildings, up to the entire city envelope, mega-city regions and systems of cities. The research offers new thinking and tools to the industry and practitioners in implementing a vision for a sustainable city. The work described in this article represents a new phase in managing urban environmental risks with precision: simulation-based tools for diagnosis and prognosis of environmental driving factors of urban form; linkages of driving factors to outcome measures such as energy, human health and wellbeing; optimization of urban form, building massing and the design of open spaces to advance sustainability goals. The on-going work demonstrates the following

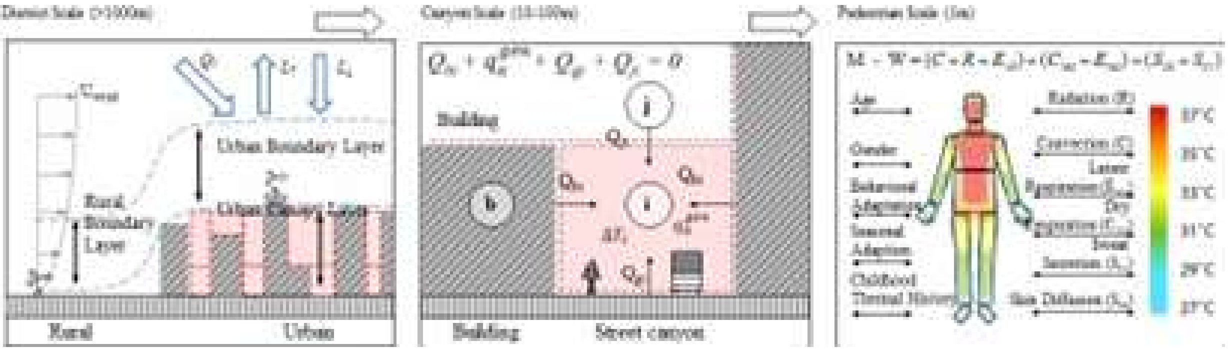

Fig. 4 SHDC develops multi-scale simulation software tools for sustainable planning and design practices, by Jianxiang Huang, Phil Jones, Yiming Sun.

pathways through which digital technologies can empower professionals and advance sustainable planning and design.

☐ Evaluate planning and design performance

☐ Measure environmental exposure and health

☐ Protect communities against climate change

☐ Optimize design schemes

☐ Web-based mapping of urban dynamics

☐ Envision low-carbon high-density future

☐ Reflect on classic theories

1. Evaluate planning and design performance

In high density cities, large development projects modify environmental attributes in systematic ways, to an extent that exceeds the capacity of guesswork or personal experiences. Performance simulation software can be powerful tools for sustainable planning and design. They are especially suitable to answer the "what if" question, allowing decision makers to assess environmental performances of proposed developments. Existing assessment software, however, is often computationally expense and overly complicated for non-technical users. As a results, performance simulations have often been left to external consultants at the end stage, after most design decisions are made.

The SHDC researchers have developed a series of software tools in support of urban planning and design practices at early stages. These tools were based on self-developed numerical models published in peer-reviewed scientific journals, rigorous field evaluation studies, and equipped with Graphical User Interface as Plugins for popular design software such as Rhinoceros and SketchUp. Planners and designers can operate the software tools using early-stage inputs, i.e. building massing models and site information. These software tools are used by leading design practices in projects both locally and overseas

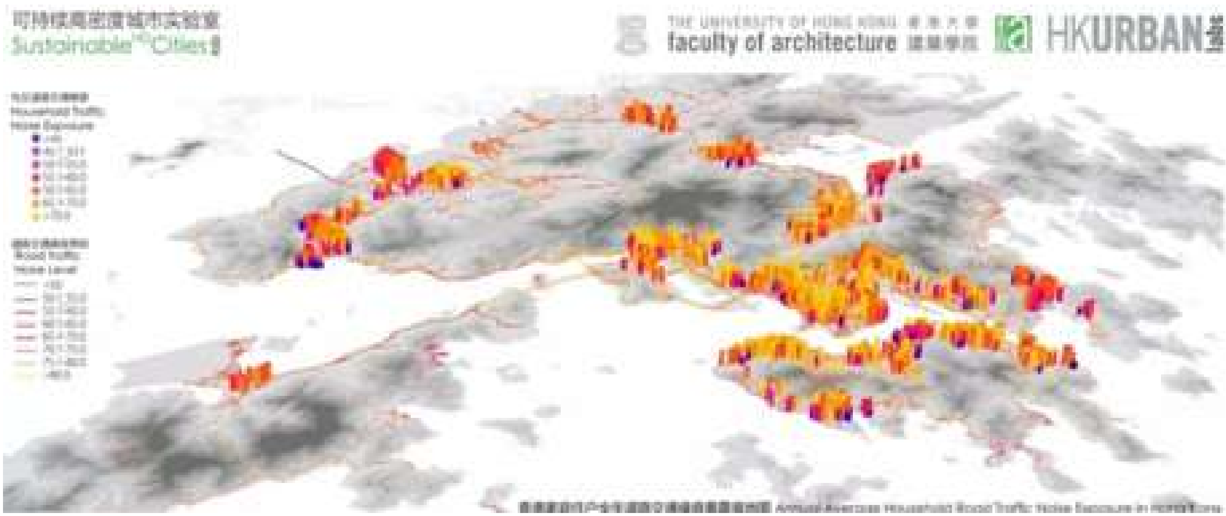

Fig. 5 Simulation of household road traffic noise exposure in Hong Kong, by Mengdi Guo, Jianxiang Huang, Michael Ni

and they were applied in the teaching of master-level curriculum at the University of Hong Kong. Examples include CityComfort+ [19], a ray-tracing model for urban microclimate and outdoor thermal comfort, the urban-scale building energy assessment tool Virvil [20], and the coupled simulation model for urban microclimate and building energy UrBEC [21].

2. Measure environmental exposure and health

The built environment is considered the "first cause" for chronic disease. The rapid change of lifestyles and health-related behaviours such as walking or leisurely activities drastically alters patterns of health in contemporary cities. In the UK, the ensuring of public health in Industrialized cities was the primary driving force in the shaping of urban planning. The Public Health Act was enabled in1875, before the promulgation of the Housing and Town Planning Act of 1909, which marked the beginning of modern urban planning. The focus on healthy cities has returned to the frontier of planning research in recent decades. SHDC has contributed to this by conducting interdisciplinary research with collaborators from the Faculty of Medicine and Engineering to map environmental exposure of noise, heat, air pollution and linkages to health outcomes (Fig. 5).

3. Protect Communities Against Climate Change

The overlap of the urban heat island effect and global climate change imposes new challenges to the urban environment, such as stagnant ventilation, lack of daylighting, urban heat, air pollution and poor hygiene. Those challenges

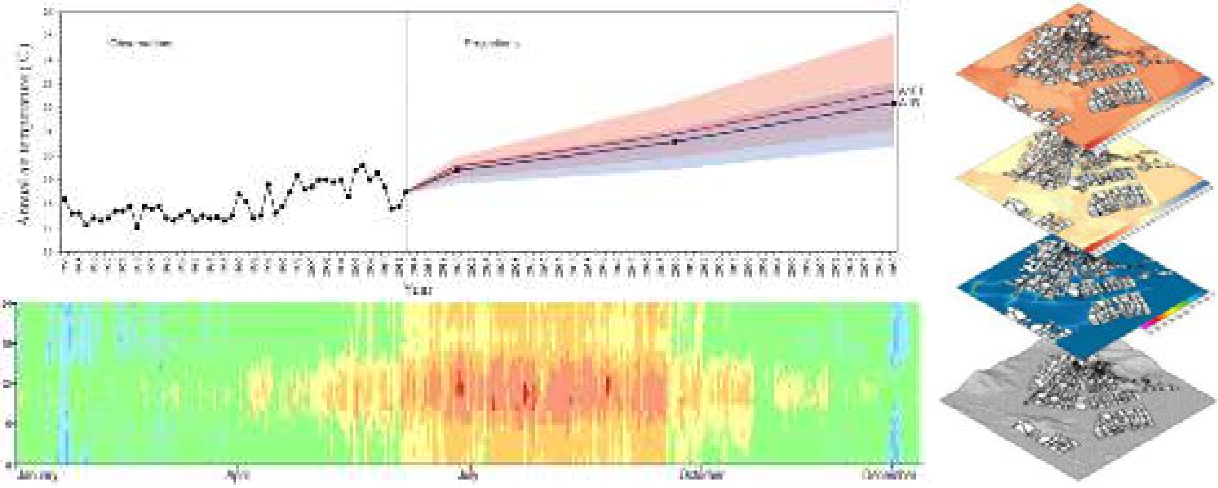

Fig. 6 Forecasting urban heat wave and air pollution for Yueqing, China, based on IPCC climate change scenarios. Source: Jianxiang Huang, Yali Wang, Rong Peng, Yiyang Yang, John D. Spengler, Linda P. Tomasso

were driven by the modifying effects of dense cities, such as the "urban canyon effect" and numerous anthropogenic heat sources, i.e. traffic and building HVAC systems. Stagnant air raises the concentration of heat exhaust and air pollutants on streets, increasing risks for infectious diseases. Researchers from SHDC used new software tools to forecast the impact of future climate change on people and the urban environment as well as to evaluate the effectiveness of mitigation measures.

4.Optimize Design Schemes

Advancement in digital technologies such as simulation and urban big data provides new opportunities for practitioners. The increasingly sophisticated tool begs the question of how can analysis lead to diagnosis and eventually drive design innovation. The SHDC team have experimented with a new design-simulation workflow, in which human designers are empowered by simulation results in a rapid feedback loop; performance evaluation results drive design revision, and the process repeats iteratively until it converges (Fig. 7).

5.Web-Based Mapping of Urban dynamics

Urban systems are among one of the most complex subjects in scientific research. Cities are under constant transformation and evolution, yet traditional urban research often relies on small, discrete, or static samples. Urban big data provides new means for measuring city dynamics. The SHDC team developed new digital tools for data-mining, topics modelling, and sentiment analysis; the new tools are used to monitor resident response to urban environ-

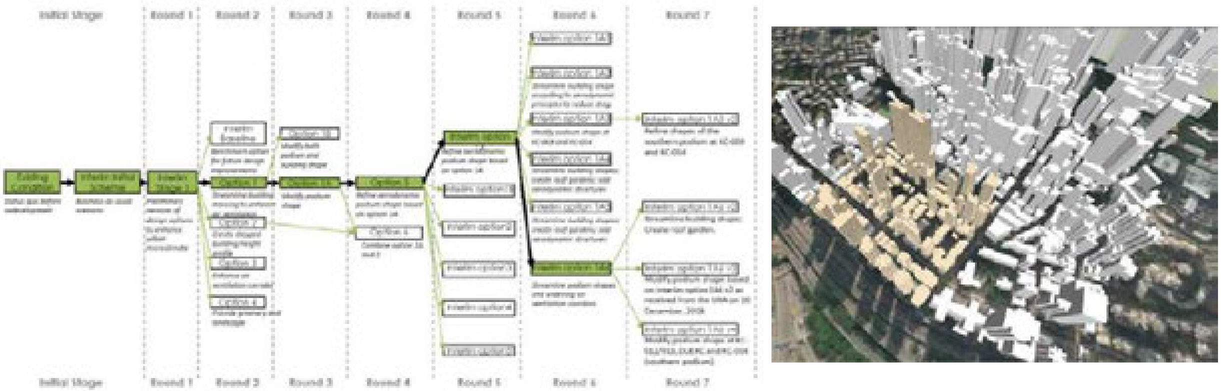

Fig. 7 A prognostic simulation-design workflow to optimize design options for Hong Kong Urban Renewal Authority. Source: Jianxiang Huang, Tongping Hao, Shan Shan Hou, Phil Jones

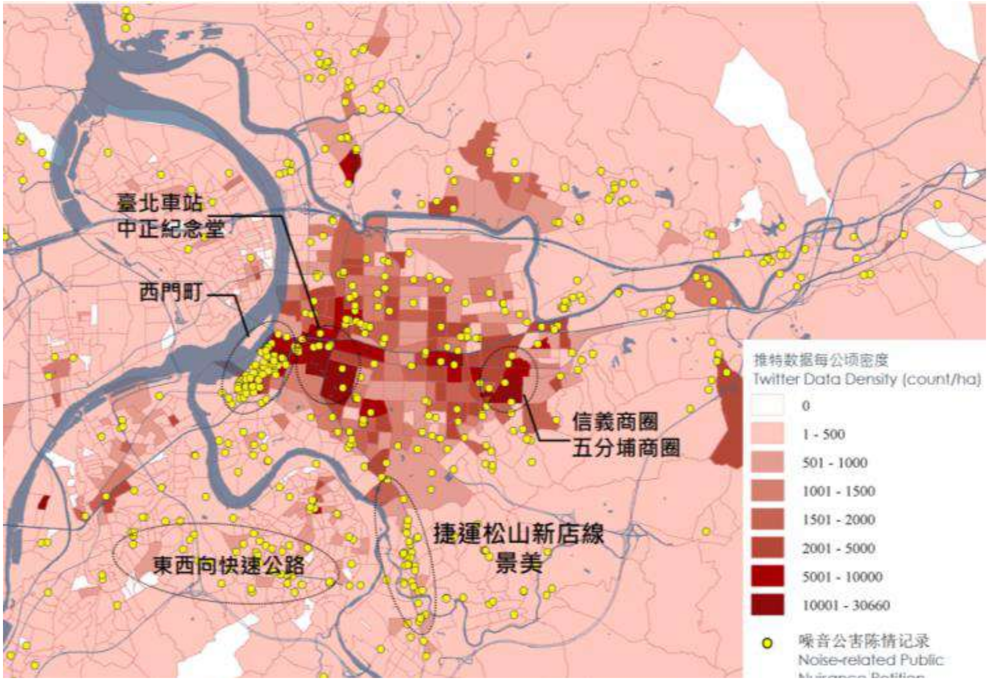

Fig. 8 Spatial Distribution of Twitter Data and Noise-Related Public Nuisance Petition in the Greater Taipei Area. Source: Mengdi Guo, Jianxiang Huang, Yiming Sun, Lishuai Li, Rong Juin Shyu

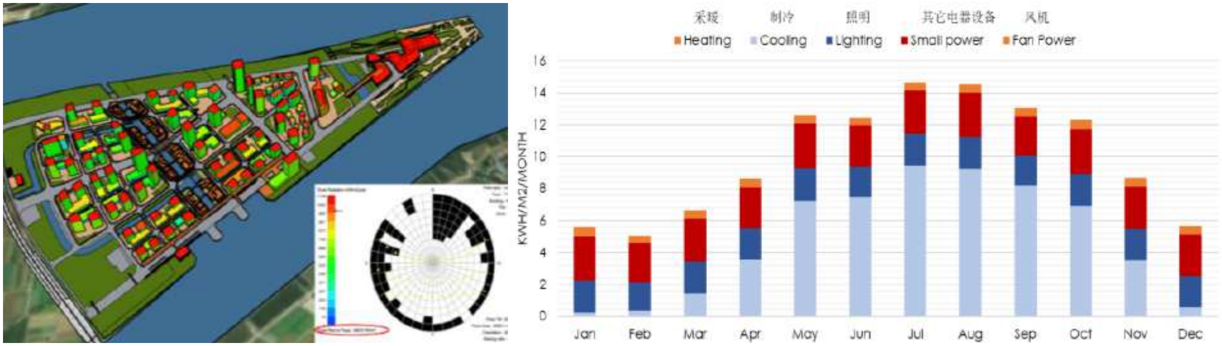

Fig. 9 Simulation of renewable energy potentials of Nansha Pearl Bay urban design project, by Xiaojun Li, Jianxiang Huang, Phil Jones

mental pollution and to support urban environmental management.

6.Envision Low-Carbon High-Density Future

Signatory states of the 2016 Paris Agreement accelerated the decoupling process from fossil fuels. To date, more than 70 cities worldwide have pledged to become "carbon neutral" by 2050. For instance, Copenhagen vows to reach the zero carbon target by 2025 using green transport and on-site renewable energy. A high density city, however, is disadvantaged in a number of ways: for example it will generally not have sufficient roof surface to collect solar energy to meet its demand, due to mutual shading from high-rise buildings. The challenge remains: how can Asian cities embrace a low-carbon, high density future?

SHDC have been exploring pathways to achieve low-carbon, high density in Asian cities in three steps: 1) reduce the energy demand from buildings and transport systems; 2) increase supply of renewable energy on-site and at the urban peripheries, such as solar, wind, and waste-to-energy; 3) adopt a systems' approach via integrated of design, building technologies, smart grid, energy storage, etc.

Fig. 10 Evaluation of Kevin Lynch's city image theories using multiple evidence from "big data" and "small data", by Jianxiang Huang, Hanna Prondzynaska, Dorota Kamrowska-Zaluska, Yiming Sun, Lishuai Li

7.Reflect Classical Theories

Urban theories are the corner stones of planning and design education. The majority of classic urban design theories taught in schools globally emerge in the Anglo-American context[22]. In the Greater Bay Area, the cultural, social and climate context differ significantly from those of the Anglo-American cities; advancement of technologies and lifestyle changes further add to the theoretical challenges. To test the relevance and applicability of classic theories in the digital age remains a pressing issue for practitioners and educators. SHDC applies novel data to reflect, evaluate, and advance planning and design theories pertinent to relevant urban context. On-going research put the following theories to test: Jane Jacob's "The Death and Life of Great American Cities", Kevin Lynch's "Image of the City", and thermal comfort and adaptation theories in urban open spaces.

Discussion

The SHDC approach constitutes one aspect of what "sustainable city" entails. Parallel insights can be argued from political, social, and economic perspectives. The SHDC believe that management of environmental risks is important to sustain a high density city. As a living laboratory, Hong Kong's lessons and experiences can contribute to the future of the urban planet that humanity as a whole is heading towards. Aside from top-down policy agendas, the SHDC advocate that bottom-up innovations, industry buy-ins, and the trickling down to communities are equally important in order to deliver a lasting impact to society. The perceived gap between the top-down and bottom-up approaches presents major opportunities for the industries and practitioners, for urban designers, planners, architects and developers alike to embrace new technologies. It is also an opportunity to reflect on the education of designers to which SHDC as an academic unit is dedicated to. Future practitioners need to be better bestowed with these news skills, tools and mind-sets.

Reflection

The Sustainable High Density Cities Lab (SHDC) is a response to challenges arise from environmental risks of a high density city: pollution, heat, disease, etc. Such risks are expected to escalate when global metropolis grow larger, denser, and, by necessity, taller. Our research offers new thinking and tools to the industry and practitioners in implementing the vision of a sustainable city. The work described in this article represents a new phase in managing urban environmental risks with precision: simulation-based tools for diagnosis and prognosis of existing and proposed development schemes; harnessing the power of new data sources to capture dynamics of cities; optimization of urban form, building massing and the design of open spaces to advance sustainability goals.

Despite forward-looking policy agendas and innovative projects spearheaded by the public sector, we believe bottom-up innovations, industry buy-ins, and the trickling down to communities are equally important in order to deliver lasting society impact. The perceived gap between the top-down and bottom up approaches presents major opportunities for the industries and practitioners, for urban designers, planners, architects, developers alike to embrace new technologies. It is also an opportunity to reflect on the education of designers to which SHDC as an academic unit is dedicated to. We need to better bestow future practitioners with the right skills, tools, and mind-sets.

The SHDC approach represents one aspect of what "sustainable city" entails. Parallel insights can be argued from political, social, and economic perspectives. We believe the environmental aspect is important to sustain a high-density city like Hong Kong, a living laboratory for other dense cities or dense- city-to-be. Hong Kong's lessons and experiences will contribute to the urban planet future that the humanity is heading towards.

Dr. Jianxiang Huang's Biography

Jianxiang Huang is an assistant professor in the Department of Urban Planning and Design at the University of Hong Kong (HKU). He is interested in the shaping of the built environment to enhance human well-being and resource efficiency. At HKU, he leads research projects to assess the thermal, acoustic and building energy performances in high density cities. He is the author of CityComfort+, a computer simulation tool that is equipped to simulate pedestrian comfort in outdoor urban spaces. Huang holds a Doctor of Design from Harvard University, a Master in City Planning from MIT, a M.Arch and a B.Arch from Tsinghua University.

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