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Smart City Visioning and Design to Enhance Sustainability, Resilience, and Community Wellbeing: A Comparison of Bangkok, Thailand, and Singapore through a Smart Environment and Smart Mobility Lens

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Abstract

Smart City characteristics, as exemplified by Smart Environment, in the form of green space, and Smart Mobility, as described by Transit-Oriented Development (TOD), are compared for Singapore and Bangkok. The two cities have different histories, social, cultural, economic, and physical attributes that are reflected in their Smart City Planning approach. Singapore has an efficient, top-down approach that can be business-friendly, while Bangkok is more of a hybrid that reflects aspects of national and local-level governance, but also includes the private sector. Despite differences in planning and governance systems, and progress towards Smart City development, endpoints of the Smart City visions embraced by the two cities have some distinct similarities with respect to Smart Mobility and Smart Environment. These similarities include consideration of green space, TOD, ICT (Information and Communication Technology) applications, and "smart hubs" that link the private sector and institutes of higher education, as part of the Smart City movement. While ICT technology is demonstrated to have an important role in assessing Smart Environment performance and seamless public transit, we emphasize that community consultation is essential in shaping the Smart City path and framing the support role for ICT. As illustrated in our case studies, it can be concluded that a Smart City design philosophy provides a rich diversity of opportunity to enhance sustainability, resilience, and wellbeing of a community with respect to future disruptions, including climate change and pandemics.

Keywords

Smart City; Sustainability, Resilience; Transit-Oriented Development; Urban Green space; IoT

1. Introduction

Singapore has been featured in the mass media and critically examined in the academic literature as a leading example of a modern, Smart City (Gooneratne, 2019; Yee, 2019; Chang & Das, 2020; Demirel, 2023; Jiang et al., 2023; Thales Group, 2023). But, what does it mean to be a "Smart City"? Certainly, Information and Communication Technologies, or ICT, play an important role in Smart City development (Batty et al., 2012), but how central is that role? Is it the main driver and focus or instead does it play a support role? Stübinger and Schneider (2020) noted that their search of "Smart City" in the Google Scholar database produced more than 2,500,000 hits; and yet the definition and characterization of Smart City continue to be debated (e.g. Albino et al., 2015; Kummitha & Crutzen, 2017; Joss et al., 2019; Mora et al., 2019; Das, 2020). Our position in this paper, and outlined in more detail previously (Chang & Das, 2020; Irvine et al., 2022a), is that Smart City development must emphasize an approach that is community-focused and participatory, in which ICT plays a support role that enhances sustainability, liveability, wellbeing, and resilience.

Smart City should in some way be entwined with the concepts of sustainability, liveability, and resilience, yet, as with the definition of Smart City, characterizing smart sustainable, or smart resilient cities remains contentious (Haarstad, 2017; Angelidou et al., 2018; Martin et al., 2018; Khan et al., 2020; Lopez & Castro, 2021; Zhu et al., 2020). Indeed, as individual concepts related to community development, it has been argued that resilience and liveability have ambiguous definitions (Tan et al., 2014; Meerow et al., 2016; Ahmed et al., 2019; Higgs et al., 2019) that potentially render the terms meaningless in practical application. In this paper, we use the United Nations Development Programme (UNDP, 2013) definition of resilience: "an inherent as well as acquired condition achieved by managing risks over time at individual, household, community and societal levels in ways that minimize costs, build capacity to manage and sustain development momentum, and maximize transformative potential." This definition includes consideration at different societal scales and accommodates the idea of build back better or bouncing forward (Hynes et al., 2020; Zhao et al., 2020). Furthermore, to guide our understanding of wellbeing in the paper, we refer to the Canadian Index of Well-Being whereby wellbeing is "The presence of the highest possible quality of life in its full breadth of expression focused on but not necessarily exclusive to: good living standards, robust health, a sustainable environment, vital communities, an educated populace, balanced time use, high levels of democratic participation, and access to and participation in leisure and culture" (Smale & Hilbrecht, 2014).

Irvine et al. (2022a) employed a 7-pillar approach to characterize Smart City for their recent project in Thailand: Smart Environment, Smart Economy, Smart Energy, Smart Mobility, Smart People, Smart Living, and Smart Governance. Furthermore, they conducted a literature review of existing Smart City Indexes and found that measures of internet access/smart phone use, green space, health care access, energy use, employment in creative industries, and green mobility share, were the top most frequently included indicators amongst the 542 identified. In consideration of space and depth of discussion, we have elected to focus on two smart pillars in this paper, Smart Environment and Smart Mobility, although we will illustrate how the other pillars are interconnected. Irvine et al. (2022a) reported that the most frequently cited Smart Environment indicator was green space, and surprisingly, this indicator was second most frequent (tied with health care access) after the measure of internet access/smart phone use.

Given this background, the objective of our paper is to illustrate and clarify how Smart City concepts are directly connected to considerations of sustainability, resilience, and community wellbeing. We expect that this objective will clarify some of the uncertainties identified with the definitions and interactions of Smart City, resilience, and community wellbeing; in effect, providing rationale for Smart City implementation. In addressing this objective, we take a case study approach by comparing Smart City initiatives associated with green space (Smart Environment) and Transit-Oriented Development (Smart Mobility) in Singapore and Bangkok. This comparison is novel in that we examine Smart City approaches for two Southeast Asian nations that have their own uniquely regional setting. Frequently, Smart City comparisons are made for the Global North, and while Singapore often is included in such case studies, normally the comparison is with a western country, or a more developed Asian country such as China or Taiwan (Dameri et al., 2019; Johnston, 2019; Noori et al., 2020; Kubina et al., 2021; Shamsuzzoha et al., 2021; Simonofski et al., 2021; Orejon-Sanchez et al., 2022; Demirel, 2023; Jiang et al., 2023).

We examine Transit-Oriented Development (TOD) and green space planning and implementation in Singapore and Bangkok, addressing both broader, general trends, and using a specific case study for each, to frame a critical comparison of the approaches being pursued to achieve their Smart City goals. We note that the discussion for Bangkok represents a departure from traditional Smart City research in that it includes presentation of the visioning and design process for possible futures, following the Research through Designing paradigm (Lenzholzer et al., 2013; Irvine et al., 2022a; 2023; in press) that specifically addresses questions such as “How does a design have to function to fit natural processes (e.g., climate, hydrology, ecology)?”; How does a large scale design intervention work within a landscape system?”; or “Can the design bring about a shift in people’s sensing, thinking or behavior?”.

2. Methodology

We used a hybrid, integrative reflection approach for this paper, in which an integrative literature review (Torraco, 2005; Whittemore & Knafl, 2005; Snyder, 2019) is the principal research tool that is supported by primary data collection and reflections from the authors’ own Smart City research projects. The research framework and workflow are summarized in Figure 1. An integrative review has the objective to assess, critique, and synthesize the literature on a research topic in a way that enables new perspectives to emerge, where in our case we compare Smart City initiatives and progress between Singapore and Bangkok. Although we relied heavily on directed searches from the peer-reviewed literature, we also incorporated government reports, mass media reports, and open-access, web-sourced data. Google Scholar was used for the peer-reviewed literature search with keywords including “Singapore Smart City”, “Bangkok Smart City”, “Transit-Oriented Development”, “Car Congestion in Thailand”, “Mass Transit in Thailand”, “Urban Green Space” “Nature-based Solutions”, “Research through Designing”, “Community Wellbeing”, and “Resilience”. More than 375 articles were identified as relevant, reviewed and synthesized in this process, with the principal 105 references being reported in this paper. We strove to include the most recent literature in our review (73% of the references are between 2019 and 2025), but we did not discount earlier references that included important historical perspectives and theory.

Primary data collection and design work for Thailand occurred in association with the Nava Nakorn Smart District and Benjakatti Park Nature-based Solution ecosystem services assessment projects. For the Nava Nakorn project, surveys were conducted face-to-face and online with a total of 770 community members and industry representatives. These surveys were used to guide the community development design visioning by Landscape Architecture, Architecture, Urban Design, and Design, Business, and Technology Management studio classes in the Faculty of Architecture and Planning at Thammasat University. The face-to-face surveys were conducted with Nava Nakorn residents (n=241) by students from the Urban Design program between February and mid-March, 2020, and completed just prior to Covid restrictions. The online surveys were conducted by students from the Urban Design and Design, Business, and Technology Management programs between end-March and April, 2020. It was necessary to conduct these surveys online due to Covid restrictions. The online surveys were administered to two separate groups, the general Nava Nakorn and Thammasat University communities (n=506) and Nava Nakorn industries (n=23). The survey and design methodologies are discussed in detail by Irvine et al. (2022a) and in general followed the research through designing principles outlined by Lenzholzer et al. (2013). The water quality monitoring presented for Benjakitti Park reflects the use of IoT (Internet of Things) and big data approaches to Smart City management, specifically for the case of Smart Environment. Water temperature, air temperature, specific conductivity, turbidity, and pH are being recorded at 1 minute time intervals in the inlet and outlet of a constructed wetland in the park to assess water quality treatment efficacy and the effort has been ongoing since 5 December 2023.

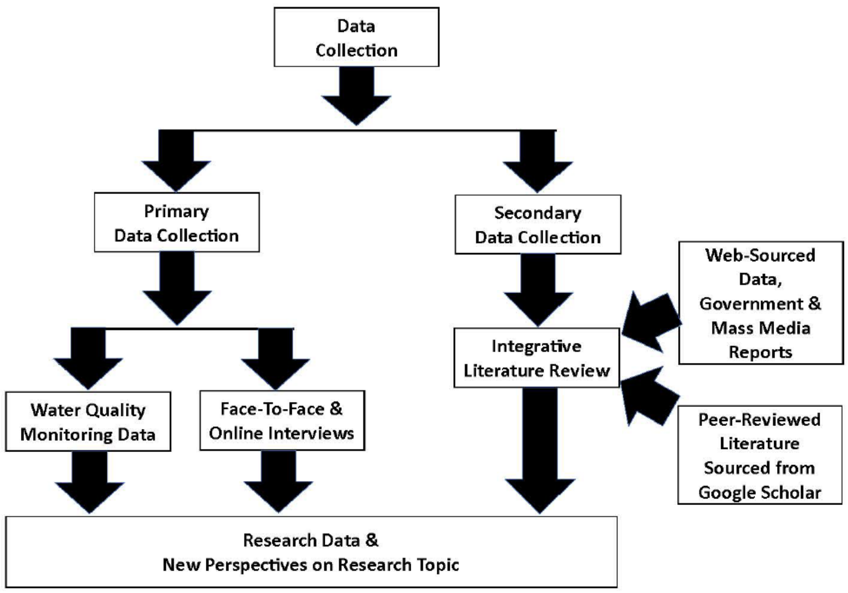

Figure 1. Research framework and workflow.

3. Discussion

3.1 General considerations of TOD and green space

Ibraeva et al. (2020) noted that TOD integrates concepts from transport engineering and planning, land use planning, and urban design to develop sustainable, convenient, and desirable transportation networks that maximize the efficiency of services by concentrating urban development around transit stations. In their discussion, Niu et al. (2019) focus more explicitly on the links with local neighborhood, suggesting TOD reflects "… a compact and mixed-use neighborhood arranged around a transit station site, which, together with the surrounding public space, is the center of the neighborhood. The transit station site serves as a transportation hub connecting the neighborhood with other areas, while the public space is an important activity and meeting place of the area." In particular, TOD seeks to reduce the dependence on automobiles and thereby accrues environmental, sustainability, and community wellbeing benefits, including reductions in greenhouse gas and PM2.5 emissions, and reduction in fossil fuel consumption (Nahlik & Chester, 2014; Nasri & Zhang, 2014; Ali et al., 2021). TOD has been linked explicitly to both Smart Growth and Smart City planning and development

(Wey, 2015; Arora et al., 2025; Suryawan et al., 2024; Ogundare, 2024; Yahia et al., 2025) as a means to achieving the afore-noted environmental, sustainability, and community wellbeing benefits. Knowles et al. (2020) acknowledge that while the concept of TOD enjoys broad appeal, barriers remain to more widespread implementation, but they also discuss some important pathways to address those barriers through Smart Mobility principles. While TOD may not be a fit for every city, it is occurring in both Singapore and Bangkok and offers a constructive ideal for guidance in developing desirable urban form.

Irvine et al. (2021) recently reviewed the non-monetary value of urban green space and noted co-benefits included better physical and mental health, enhanced community wellbeing, enhanced management of urban runoff quality and quantity, and mitigation of the urban heat island. They recommended that the non-monetary value of urban green space might be quantified using an ecosystem services approach. Irvine et al. (2020) summarized results of a hedonic pricing approach to monetize the value of wetlands (green space) in urban areas of Australia and Singapore. The hedonic pricing approach has been used extensively to monetize the value of green space (Lupp et al., 2016; Park et al., 2017; Daams et al., 2019; Sohn et al., 2020).

3.2 TOD and green space in Singapore

3.2.1 TOD

In this section, we discuss Singapore's TOD as a tool and strategy to develop well-planned transport networks through the metro train services, popularly known as MRT (Mass Rapid Transit) and extensively complemented by island-wide public bus services. Given the small size of the city-state at around 734 km^2 and with a very high population density of 8,058 persons/km^2 (Singapore Department of Statistics, 2025), Singapore has always given preference towards popularising public transport over extensive use of private vehicles. To incentivise using public transport, Singapore's Land Transport Authority keeps the fares affordable for all passengers and with subsidies for elderlies and school children. A McKinsey Report (Knupfer et al., 2018) noted that public transport is the most affordable in Singapore, according to a study of 10 major cities worldwide. Secondly, according to the same report (Knupfer et al., 2018), the public transport system in Singapore is highly efficient with the ease of ticketing and transport-related services, facilitating traveller use and navigation. Third, the number of private vehicles on the island nation is heavily controlled by the state as a means of managing traffic movement and a conscious effort is made towards a smart and sustainable transport option through increasing use of public transport. Finally, the Singapore Land Transport Authority (LTA), together with the Urban Redevelopment Authority (URA) and other government agencies are working on making public transport available within a short walking distance from every residential neighbourhood with heavy transport infrastructure development such as new bus lanes, more loop services to nearest MRT stations, and extensive network of new MRT lines with TODs playing a major role in enhancing a greener, sustainable, and efficient public transport landscape in Singapore. Singapore has continuously and incrementally deployed technologies, including private participation, to enhance TODs and efficient urban mobility (see Yuan, 1998) and these smart mobility characteristics also are linked to Smart Living through connections of community wellbeing.

The first MRT train was operationalised in 1987 and today the system covers a total distance of around 230 km together with another 28 km of light rail transit (LRT) connectivity across the island nation. While there are 8 MRT lines currently operational, many more extensions and new lines either are planned or under construction (Figure 2). One of the important lines under construction is the RTS (Rapid Transit System) Link between Woodlands in Singapore's north to Johor Bahru in Malaysia that will help in seamless travel between the two countries with a capacity to serve 10,000 commuters every hour. The RTS Link has been well-planned as part of a larger TOD development and connected to existing travel networks and to civic amenities around the Woodlands neighbourhood for a seamless and efficient public transport experience. The RTS Link should be ready for commercial operation by the end of 2026. As Kidokoro (2020) noted, multimodal and efficient connectivity has been prioritised in Singapore's TOD planning and development.

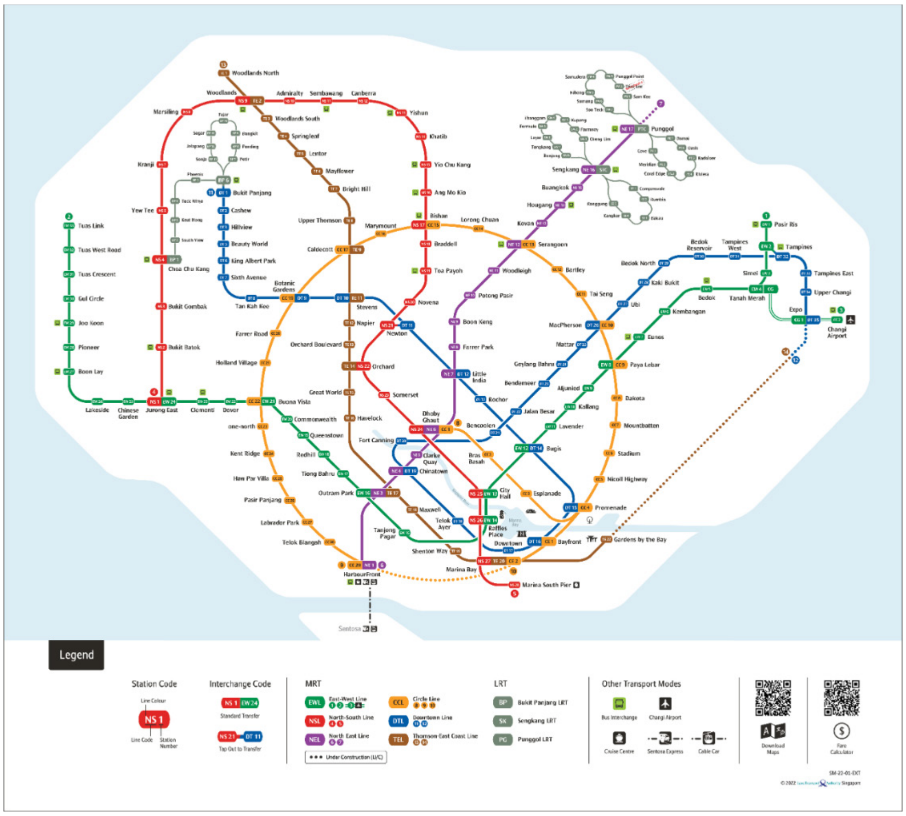

Figure 2. Singapore's MRT system as of 2024 (Source: Land Transport Authority, Singapore).

Singapore's TODs consist of an extensive network of buses with around 350 bus routes that connect the nook and corners of the island nation. The majority of bus routes are planned in a way that connects most of the MRT lines across its routes so that it provides an efficient and seamless connectivity between various modes of public transport. Singapore bus services increasingly are investing in sustainable resources and therefore, electric and hybrid buses are being used across the island, consistent with Smart Energy principles. Singapore's TOD system also has been complemented by modes of active mobility such as bicycle and walking routes that connect neighbourhoods to the nearest bus stops and MRT stations for seamless and sustainable travel options.

3.2.2 Green space

From the independence of Singapore in 1965, the city-state has initiated an integrated and centralised urban planning approach through the Garden City concept, including extensive green coverage across the island. The idea was to provide green and shade to the increasingly developing urban landscape, residential, and industrial buildings. Roads were well-planned with trees along the pedestrian routes for better shade and cooling (Er, 2021).

By 1998, the Garden City concept evolved into the ‘City in a Garden’ concept, with Singapore envisioned as a bustling metropolis nestled within a green oasis (O’Neill, 2023). This evolved vision led to new architectural development which beautified buildings skywards through the additions of green walls, rooftop gardens, and sky terraces (O’Neill, 2023). In 2020, the Singapore National Parks Board (NParks) introduced the next evolution of the concept in the form of the ‘City in Nature’ vision which aimed to ensure a green, liveable, and sustainable home for future generations of Singaporeans (Er, 2021). The bold new vision builds towards increasing the number of trees, parks, and green spaces around the city (Er, 2021).

By 2015, over 47% of Singapore was covered in green spaces which consisted of parks, community gardens, nature reserves, roadside and skyrise greenery, as well as unoccupied statelands, making Singapore one of the greenest countries in the world (Gan, 2015). As of 2022, through the combined efforts of the Ministry of National Development and NParks, Singapore has planted over 540,000 trees, contains over 300 parks, 190 km of nature ways, 380 km of park connectors, 155 ha of skyrise greenery, 3,347 ha of nature reserves, and 94% of households are just a 10-minute walk away from a park (National Parks Board (NParks), 2023).

The increased green coverage across Singapore is consistent with the concept of green urbanism. According to Newman (2010), green urbanism is an approach to urban planning which leads to the development of settlements that focus on achieving harmony with nature as well as creating communities and lifestyles that are more sustainable and utilise fewer resources. One notable policy that has helped to support Singapore’s Garden City goals is the Singapore Green Plan (SGP), a comprehensive 10-year plan and a nation-wide movement launched in 1992 to balance the environmental and economic goals of the country (Leng, 1994). The plan went through two more iterations in 2012 and 2030. SGP 2012 charted Singapore’s path towards environmental sustainability through an increased emphasis on reduced waste generation and increased recycling efforts (Tortajada & Koh, 2021). SGP 2030 charted ambitious targets aimed at reducing carbon emissions, that included Smart Energy initiatives, to ensure a climate-resilient and green sustainable future with net-zero emissions (Tan, 2021).

In 2014, Singapore’s Smart Nation initiative was launched and it was aimed at infusing various information and communication technologies into both the public and private sectors, so as to improve the lives of citizens while also improving the country’s productivity, following the concepts of Smart Governance (e.g. digital government services), Smart Economy (e.g. through FinTech sandboxes), Smart Living (e.g. through smart health and the health hub), and Smart People (e.g. the web-based student learning space and SkillsFuture lifelong learning program)(Skills Future Singapore [SSG], 2025; Woo, 2020). Over the years, through the employment of digital tools and Smart Technologies, Singapore NParks has been able to achieve remote monitoring of the flora across the country as well as automated lawn management via the use of robots and sensors, ultimately helping to not only improve the productivity and lived experiences of Singaporeans but also ensure more efficient monitoring of the wellbeing of Singapore’s green spaces (Miller, 2023).

3.2.3 Case study: Punggol Digital District

One notable product of Singapore’s Smart Nation initiative is the creation of the Punggol Digital District (PDD), Singapore’s first smart and sustainable district which brings together industry and academia within the wider community, to create a green space where everyone can live, work, and play effectively (Sipahi & Saayi, 2024). The PDD design and implementation is fully consistent with TOD theory and the above-discussed green space principles. Furthermore, it aims to provide an ecosystem for key growth sectors in Singapore’s digital economy such as cybersecurity, artificial intelligence, FinTech, and smart living (Lim, 2024), thereby linking aspects of Smart Economy and Smart Living pillars.

Unveiled in 2018, the PDD is designed with an integrated masterplan and green technology to help create a more liveable and sustainable environment for the community at a local district level and foster a thriving business and lifestyle ecosystem that attracts talent and enables innovation (Smart Nation, 2024). The PDD is strategically designed to bring together the Singapore Institute of Technology (SIT)'s campus and the Jurong Town Corporation (JTC)'s Business Park, in order to create Singapore's first truly smart district (Lai & Chuan, 2018). The Business Park, in particular, was awarded the Platinum Award by the Building and Construction Authority's Green Mark Districts for adopting the highest level of sustainable design and construction strategies when constructing its low-energy green buildings (Kit, 2024). Figure 3 illustrates the construction of these green buildings.

Figure 3. The construction of green buildings at the JTC Business Park (Jurong Town Corporation [JCT], 2024)). The low-energy designs are consistent with the Smart Energy concepts of Smart City.

The district also will be served by the upcoming Punggol Coast MRT, a bus interchange, new bus stops, a 200-room hotel, a hawker centre, a community club, and a heritage trail to accommodate both locals and tourists in the area (The Business Times, 2024). The PDD aims to accelerate the pipeline of industry-ready talent by encouraging students and professionals to collaborate and pursue new, creative ideas that can be readily tested and utilised by businesses within the PDD (Smart Nation and Digital Government Office, 2025a). Spanning 50-hectares, the PDD is envisioned as a mini-Silicon Valley, where it is the centre of digital and cybersecurity industries and is expected to generate 28,000 high-tech jobs as well as accommodate 12,000 SIT students (Tan, 2024).

The PDD features some notable district-wide infrastructure and services aimed at achieving sustainability, the first of which is an Open Digital Platform that will integrate the management of the various buildings within a single estate system, as well as centralise the data collection of these systems allowing innovators to plug into the platform and access the data to create community-centric solutions (Urban Redevelopment Authority [URA], 2025). Secondly, the PDD will feature a District Cooling System which centralises cooling needs and reduces the district's carbon footprint (URA, 2025). Thirdly, the PDD will feature Pneumatic Waste Collection via a district-wide underground vacuum-pipe network which will eliminate the need for waste collection trucks and remove odour from refuse chutes (URA, 2025).

Fourthly, the PDD will contain a Smart Energy Grid that enables consumers to adopt clean sources of energy for daily use (e.g. charging electric vehicles) and achieve greater energy efficiency and savings through smart metering (URA, 2025). Fifthly, the district will see Singapore's tallest industrial building constructed with timber, resulting in a carbon performance that is 98% lower than the benchmark level set for non-residential buildings (The Business Times, 2024). Lastly, the whole district is designed to be 'car lite', with shared car parks and vehicular access roads located underground to free up the ground level for public-use, bicycles, and pedestrians, ensuring that there are 50% fewer carpark spaces than a normal estate (The Business Times, 2024).

Through the integration of green spaces and smart infrastructure across its district, the PDD will be able to keep its energy consumption levels and carbon footprint low, ensuring that it is highly liveable and environmentally sustainable for everyone (Lim, 2024). The smart and sustainable initiatives implemented in the PDD will act as a pilot project to determine if the model can be applied to other districts in the future so that Singapore may reach its national net-zero goal by 2050 (Lai & Chuan, 2018). Figure 4 illustrates the PDD's district-wide sustainability.

Figure 4. The PDD's district-wide sustainability (Source: (JCT, (2024)).

The PDD will open in phases, with the first phase beginning from September 2024 and so far, 65% of the spaces have been taken up for both the business park and retail spaces (Lim, 2024). In addition, the Oversea-Chinese Banking Corporation (OCBC) is investing about S$500 million into building its new innovation hub in the PDD as well as partnering with SIT to drive innovation and talent development in FinTech via the establishment of a learning lab and providing scholarships, further contributing to the collaboration between industry and academia within the wider Singapore community (Goh, 2024).

3.3 TOD and green space in Bangkok

3.3.1 TOD

In this section we focus our discussion on the city of Bangkok (BMA) and Bangkok metropolitan region (BMR), the five provinces comprising the peri-urban area of BMA, as collectively they represent the primate area of Thailand. However, in discussing Smart City policy, we must acknowledge that the Thai Digital Economy Promotion Agency (DEPA) very much emphasizes Smart City projects in secondary cities. The traffic congestion of Bangkok globally is well-known and there appears to be a number of factors that contribute to this situation, including fragmented, weak, and unequal governance of the transportation system; the uneven geography of transportation nodes and public transportation (including small road area ratios); and planning that favors automobile use (including underpriced parking)(Pujinda & Yupho, 2017; Marks, 2020; Ayaragarnchanakul & Creutzig, 2022). Suggestions to alleviate the congestion have included increased parking rates, traffic surge toll pricing, improved driver training, and undertaking land readjustment projects to widen small roads, increase road connectivity, and upgrade road area ratios to be more consistent with major cities such as New York and Tokyo (Pujinda & Yupho, 2017; Marks, 2020; Bhu-Anantanondh et al., 2021; Ayaragarnchanakul & Creutzig, 2022).

However, aspects of TOD also should be considered. Public transit in BMA/BMR consists of a somewhat overwhelming array of options and connections, including motorcycle taxi, tuk tuk, automobile taxi, red trucks (backs of pick-up trucks with seating), public vans, public buses, BTS (skytrain), and MRT (Metropolitan Rapid Transit). In 2022, an average of approximately 401.4 thousand passengers used the BTS per day, up from 216.4 thousand in 2021 (Statista, n.d.), as the result of reduced Covid restrictions. On a peak day in February, 2023, ridership reached 1,577,330 (Abhasakun, 2023). If we consider that the BMA/BMR population is approximately 11 million people in 2023 and assume most users will undertake a round trip, even on the peak day, ridership represents only 14% of the population. First opened in 1999, the BTS has expanded its service to include about 68 km of track, now reaching north to Khu Khot in Pathum Thani province, approximately 30 km from downtown Bangkok and south east to Samut Prakan province. The MRT operates approximately 136 km of line that includes hybrid subway and monorail. MRT ridership in 2022 averaged 266.2 thousand passengers per day (Statista Research Department, 2024b). A number of the BTS and MRT stations are linked with shopping malls in the downtown area. The primary bus and van services for BMA/BMR are operated by the Bangkok Mass Transit Authority, with 118 routes, 3,000 buses, and approximately 3 million riders per day. Although gradually being replaced, many buses are aging and do not have air conditioning.

Kidokoro (2020) noted that an effective transit network under TOD must include multimodal connection planning and as such, connectivity is an important element of TOD. Although elements of TOD have emerged in Bangkok (e.g. around the new Khu Khot BTS station (City Cracker, 2022)), a number of barriers remain. For example, Marks (2020) noted that the condition of the buses was a disincentive for broader use. A one-way trip on the BTS from Khu Khot to downtown is 62 THB ($1.73 USD). Beginning 1 January 2024, the daily minimum wage for workers in the BMR increased by 10 THB, from 353 to 363 THB ($9.87 USD to $10.15 USD). With a round trip representing 34% of the daily minimum wage, use of the BTS is cost-prohibitive to lower income workers. Connection to a bus stop or MRT/BTS station may be accomplished through walking, or very often, an inexpensive motorcycle taxi ride. Nyunt and Wongchavalidkul (2020) examined 43 different TOD variables that potentially could influence BTS/MRT ridership and found population density, whether the station was an interchange station, number of bus lines, number of bus stops, number of railway stations, and park-and-ride buildings were significantly correlated with ridership. Iamtrakul and Zhang (2014) reported that walkability influenced the decision to use mass transit, a finding similar to that reported by Goh et al. (2022) for bus ridership in Phnom Penh, Cambodia. Finally, we note that while the proximity of interchange nodes does enable transfer between different modes of transport, the systems are owned by different operators, so payment using a single, digital passcard is not possible.

3.3.2 Green space

The loss of green space over time in the BMR has been well-documented through remote sensing. For example, Kamal et al. (2017) used the Normalized Difference Vegetation Index (NDVI) with Landsat and HJ-1A satellite imagery to determine that green space for the BMR decreased by 348 km^2 (a 42% loss) between 1994 and 2012. Khamchiangta & Dhakal (2020) also used Landsat and NDVI to conclude that vegetated area loss in the BMR between 1991 and 2016 was 88 km^2, while bare land loss was 288 km^2. Likitswat & Sahavacharin (2023) examined eight 25 km^2 test sites in the peri-urban fringe of BMA using airphotos taken between 1952 and 2017 and found green space loss ranged between 4 and 59%, with the largest losses being in Pathum Thani province that continues to experience rapid build out from BMA spillover.

Nguyen and Chidthaisong (2024) concluded that green space in BMA is around 7.6 m^2 per capita, considering all types of urban vegetation and informal green spaces and 3 m^2 per capita when only public green space is considered. This green space area is less than the minimum 9 m^2 per capita recommended by the World Health Organization (WHO) and the 56 m^2 per capita in Singapore (Kraitong, 2023). Encouragingly, the BMA has proposed 124 locations for pocket park development that would increase green space by approximately 1.1 million m^2 and also has implemented the "Green Bangkok 2030" policy to facilitate public/private/civil partnerships with the goal of adding 18 million m^2 of green space in 11 pilot projects (Nguyen & Chidthaisong, 2024).

This focus on green space certainly is encouraged by recent additions of high-profile Nature-based Solution designs, including the stormwater management park at Chulalongkorn University, the PTT Metro Forest, the green roof agrihood at Thammasat University, the Forestias suburban community development, Chong Nonsi canal park, and Benjakitti Forest Park. Located in downtown Bangkok, close to Lumphini Park and One Bangkok, and adjacent to the Queen Sirikit Convention Centre, the most recent phase of Benjakitti Park opened in 2022 and represents a 414,000 m^2 NbS green/blue space that formerly was a tobacco manufacturing facility. The park design includes preservation of existing trees and new plantings of a number of native tree species, such as Cork tree (Sonneratia caseolaris), Lumpan (Sonneratia ovate), Cassod tree (Senna siamea), Neem tree (Azadirachta indica), Bodhi or sacred figs (Ficus religiosa), Banyan trees, Yangna (Dipterocarpus alatus), and Iron wood (Hopea odorata). A constructed wetland system contains a series of four connected cells that can help treat water diverted from the local khlong (canal) system, Khlong Phai Singto, (up to 1,600 m^3per day) and has a design capacity to store 128,000 m^3 of stormwater runoff. The distinctive, Chinese-inspired ponds and mounds wetland design (Yu & Wang, 2024) can be viewed from an extensive boardwalk system that also provides exercise opportunity (Figure 5).

We recently undertook a research initiative that will quantify the ecosystem services provided by Benjakitti Forest Park, including water quantity and quality management, urban heat island mitigation, PM2.5 management, carbon sequestration, biodiversity, noise buffering, and aesthetics assessment, following the methodology piloted by Irvine et al. (2024). This effort includes installation of floating IoT stations in cell 1 of the wetland and development of a smart phone app to monitor and visualize water quality information (Figure 6). This type of IoT application is an example of Smart City technology to verify NbS design performance, that despite claims (Yu & Wang, 2024), so far is lacking (Likitswat & Sung, 2025).

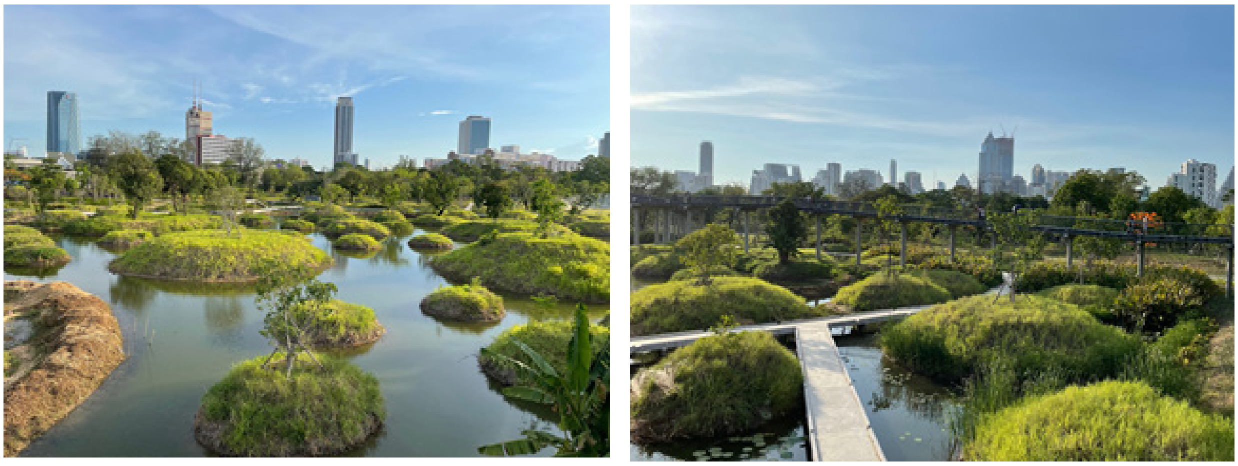

Figure 5. Benjakitti Forest Park wetlands and boardwalk system (photos by authors).

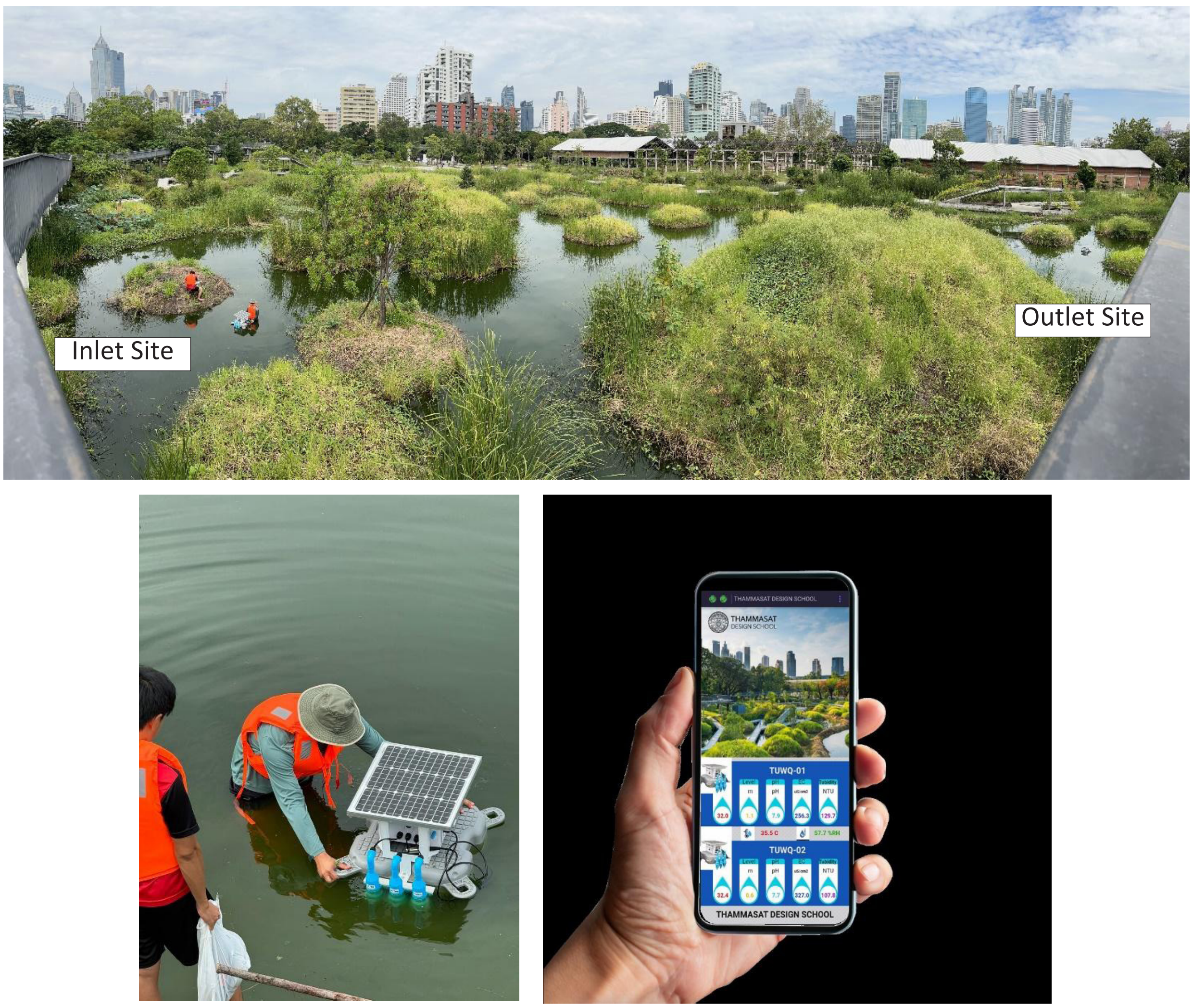

Figure 6. IoT water quality monitoring stations at Benjakitti wetland cell 1 inlet and outlet (top); close up of station configuration and water quality app (bottom)(photos by authors).

The IoT stations monitor water depth, water and air temperature, pH, specific conductivity, and turbidity. As turbidity is a measure of water clarity, it is highly correlated with total suspended solids. Results in Figure 7 illustrate that wetland cell 1 is improving water quality through filtration and settling of sediment. Spot measurements of dissolved oxygen were collected using a Hanna Instruments 9147 handheld meter at 37 sites within the four wetland cells on four dates between 19 December 2023 and 28 February 2024. The mean levels of dissolved oxygen were 2.8 mg/L, 2.2 mg/L, 2.2 mg/L, and 2.7 mg/L in cells 1 through 4, respectively. Dissolved oxygen also was measured in Khlong Phai Singto near the pump inlet to the wetlands and averaged 0.4 mg/L. We emphasize that the IoT station and dissolved oxygen measurement results represent a small snapshot in time and we will continue to monitor over the next year. Nonetheless, these preliminary results indicate that the wetlands are having a positive impact on some aspects of water quality.

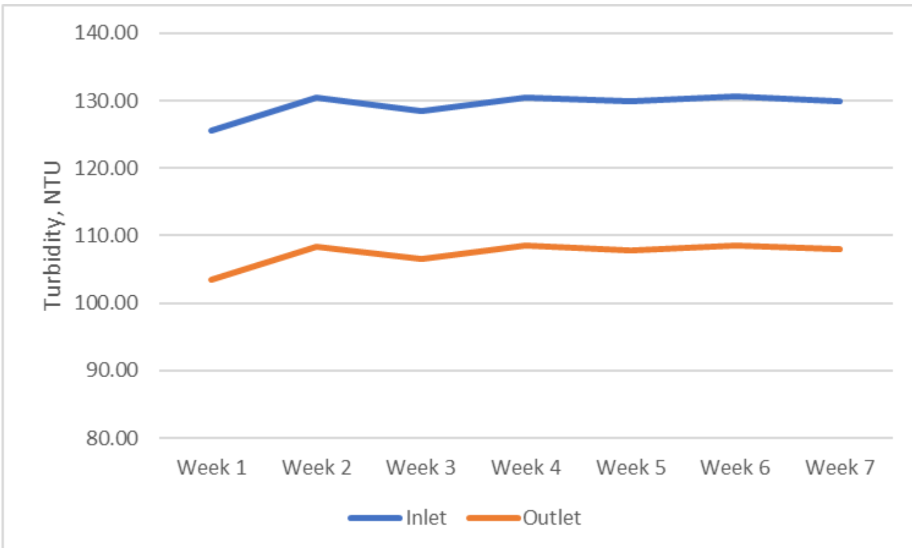

Figure 7. Weekly mean turbidity levels at the inlet and outlet of Benjakitti wetland cell 1. Monitoring period represents 5 December 2023 through 23 January 2024 at 1 minute time steps.

3.3.3 Case study: Nava Nakorn Smart City, Thailand

We undertook a Smart City project for a peri-urban superblock area approximately 55 km north of downtown Bangkok in 2020. The focus of the study was to provide design visioning and alternatives for development within the superblock using a research through designing approach. While there is a considerable body of literature on the technical and societal aspects of Smart City, this study was novel in that very little work has been done on characterizing what a Smart City might look like. This type of visioning is particularly helpful in communicating ideas to local stakeholders. The study area included the Thammasat University and Asian Institute of Technology campuses, the Thai Science Park, the Nava Nakorn Industrial Estate, and a mix of surrounding agriculture, commercial, and village land uses. Nava Nakorn Public Co. Ltd. (NNPC) manages the industrial estate and essentially acts as a combination of utility and local government, providing services that include electric power generation, potable water, wastewater treatment, solid waste management, road construction and maintenance, community security, and fiber optic communication. Nava Nakorn represents a mix of industrial, commercial, and residential land uses and has a population of 150,000 people. There are approximately 200 industries within the estate that generally represent the light, high value sector.

As a first step to inform the design work, the project team undertook the series of community face-to-face and online surveys noted in the Methodology. The face-to-face survey showed that a large proportion of the respondents owned a car (45.6%), while motorcycle ownership also was common; 16% of those surveyed do not at least own a bicycle and therefore would have to walk or take hired (public or private) transportation. Given the relatively high rate of vehicle ownership, it is not surprising that 60% of those surveyed use their own vehicle for the commute to work; 10% use a motorcycle taxi; 6% use company-provided transport; 4% use public bus; 2% use public van; and 18% use other forms of transportation (which would include walking). The large majority of those commuting to work do so alone (67%), while the remainder share the commute with family or friends. Heavy traffic in the morning and evening was reported and we expect that TOD could help to address this issue of personal automobile use.

One of the goals of NNPC for this project was to explore how Smart Mobility (and TOD) could be implemented in addressing the Thailand 4.0 national development strategy which seeks to transition the labor force into “knowledge workers”, consistent with principles of Smart Economy and Smart People. The NNPC hope was to upscale industry, in part by attracting knowledge workers who may prefer to live in BMA, but have employment within the estate. The expansion of BMA/BMR mass transit, especially the dark red regional line is key to this plan and is consistent with TOD philosophy. NNPC also expressed an interest in establishing a digital village within the estate that would act as an incubator to connect industry, local universities, and the Thai Science Park. This mass transit and digital village (Smart People) aspect of the TOD was summarized by Irvine et al. (2022a), while here we focus more on Smart Mobility within Nava Nakorn.

Based on a spatial analysis of accessibility, society, green space and ecology, water systems, and aesthetics as well as assessment of site potentials and constraints that considered trade-offs between competing interests, masterplans were developed for Nava Nakorn, an example of which is shown in Figure 8. We note here that all design work was undertaken by year 3 and 4 students in the Faculty of Architecture and Planning at Thammasat University. A detailed 3D section of the masterplan is presented in Figure 9, which shows the location of a central transportation hub relative to the digital village. Figure 10 illustrates a visioning perspective of the transportation hub, with emphasis on multi-modal mobility options.

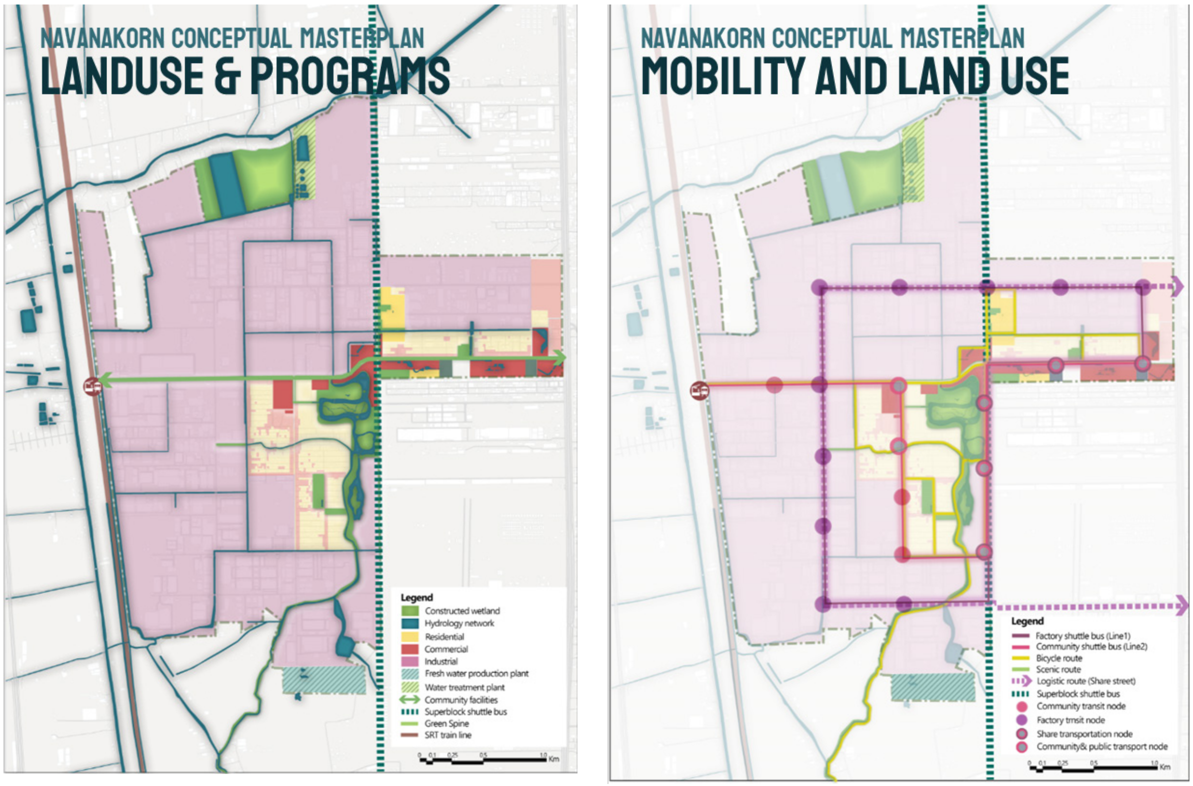

Figure 8. Nava Nakorn masterplan emphasizing Smart Mobility and connectivity with existing land use (design credits to Tanavara Chawanid, Paveena Kusaranukun, Manita Intarachaisri, and Yuto Motani, UD327 class).

The online community survey indicated that around 70% of respondents had used public areas either in Thammasat University or Nava Nakorn, but only 20% of the respondents were entirely satisfied with the public areas provided. For the face-to-face survey within Nava Nakorn, green space and recreational space were identified as deficient. When asked if there was any green space nearby their neighborhood, 59% provided an affirmative response. However, a lack of recreational space was the second most commonly cited community problem. Furthermore, the community generally did not make a connection between green space/blue space and water management. Informed by these survey results, the design teams very much focused on improving green space for the community that can provide the additional service of sustainable water management. This issue is discussed in greater detail by Irvine et al. (2022a, 2022b; 2023), but examples of the green space visioning are provided in Figure 11.

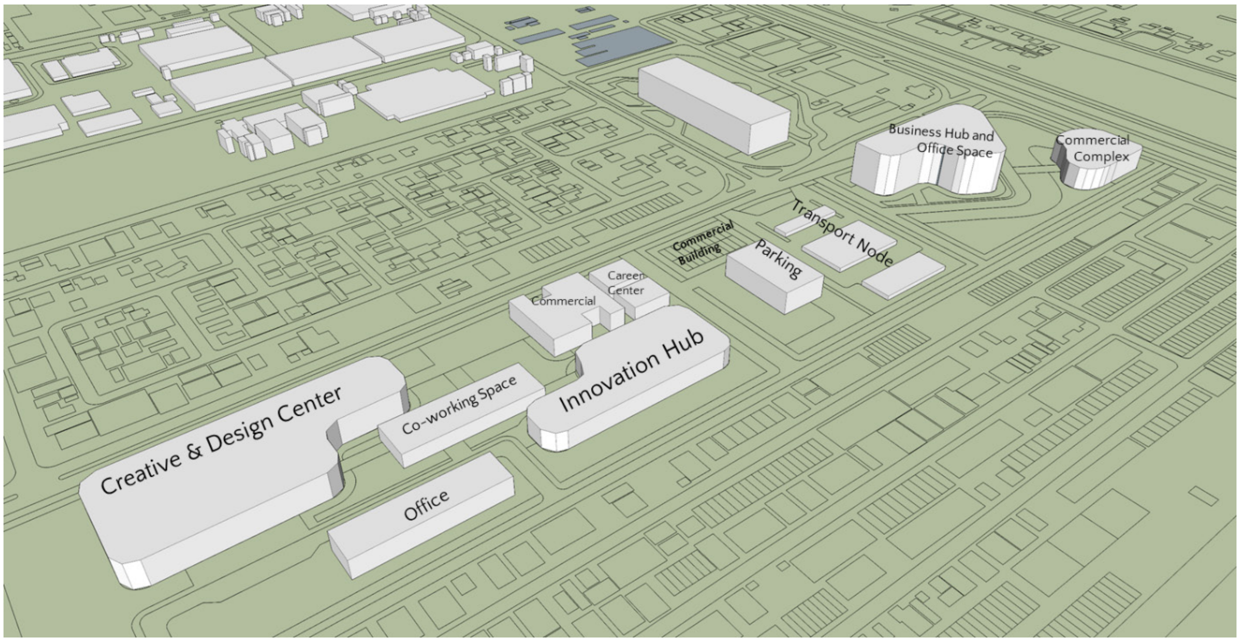

Figure 9. Spatial arrangement of the digital village and transporation hub (node)
(design credits to Tanavara Chawanid, Paveena Kusaranukun, Manita Intarachaisri, and Yuto Motani, UD327 class).

Figure 10. How the Smart Mobility transportation hub might look – a perspective on multi-modal transportation connections
(design credits to Tanavara Chawanid, Paveena Kusaranukun, Manita Intarachaisri, and Yuto Motani, UD327 class).

Figure 11. Heart of Nava Nakorn where existing pond and NNPC headquarters are re-imaged (design credits to Kanokwan Srisamer, Manus Janthik, Panyawat Terdkeat, Wipawee Khantikittikul, UD327 class).

Specifically for the visioning presented in Figure 11, we see the interconnections between transportation (Smart Mobility), Smart People (lifelong learning center), Smart Environment (water storage/water management), and most recently, Smart Energy, as NNPC has established a floating solar PV (photovoltaic) test bed that is sufficient to power the needs of the head office (Figure 12). The Nava Nakorn Center in Figure 11 could remain as the head office for NNPC, but the designers also envisioned establishing an otter conservatory as part of the complex with the goal of Nava Nakorn becoming a “pioneer district of clean water ecosystems, having ecological, social, and biophilic significance”, particularly as symbolized by the otter (and perhaps inspired by Singapore’s example). The event plaza space would be flexible enough to provide a gathering space for a variety of community-sponsored activities that would enhance a sense of place and wellbeing.

Figure 12. Recently-installed floating PV solar power system on the pond in the heart of Nava Nakorn (photo by authors).

4. Conclusion - TOD and Green Space in Singapore and Bangkok; Comparisons and Ways Forward

4.1 Purpose built vs. upscaling Smart City and differences in governance

In this concluding section we explicitly compare implementation of Smart City programs related to governance, Smart Mobility (as represented by TOD) and Smart Environment (as represented by green space) between Singapore and Bangkok, as well as ways forward. An important distinguishing feature between the two cities highlighted in the case studies is that Singapore’s new towns are purpose-built, whereas Nava Nakorn represents an incremental improvement. Indeed, Bangkok’s development has evolved more organically over time through various planning schemes, making it more of a continuous improvement than Singapore’s more recent rapid and focused modernization since the mid-1960s. In some ways, Bangkok’s incremental improvement along the Smart City path might be considered a more diverse form of upscaling. A number of studies have noted the challenges and barriers to successful upscaling of Smart City pilot projects (e.g. Van Winden & Van den Buuse, 2017; Lee et al., 2023; da Matta et al., 2024), including internal technical, organization, management, and open innovation capacity of key institutions; the affordability which will be impacted by economic, regulatory, and technological conditions; governance conditions including within-agency, between-agency, and private-public collaborations; and inclusion of community in program design and development. In this sense, purpose-built communities as in Singapore may offer an advantage, although Bundgaard and Borrás (2021) have noted that successful upscaling of Smart City programs can have different paths.

Singapore has developed a strong Smart City vision with implementation reflected through emphasis on green space and efficient, effective, and equitably-accessible public transportation that reflects TOD principles. These attributes are clearly illustrated by the Punggol Digital District case study. Singapore's dense development, while in some ways presents challenges related to natural resource availability, is offset by efficiency of service delivery. Singapore also benefits from visionary leadership that is delivered by an effective and streamline government structure. While there are arguments that Smart City should have a community-driven, bottom-up approach, Singapore demonstrates how a well-intentioned top-down approach also can deliver on community wellbeing. Bangkok has taken a different planning path as demonstrated here, which is more is incremental and may include top-down direction from national government, but also heavily involves local and regional government, and even private sector. While not as advanced along the Smart City path as Singapore, BMA/BMR is demonstrating a commitment in this direction (see also, for example, the ongoing One Bangkok development (One Bangkok, 2024).

4.2 Smart Mobility and Transit-Oriented Development comparison between Singapore and Bangkok

The challenges for BMA/BMR probably are greater to overcome than Singapore with respect to Smart Mobility, as the existing reliance on personal modes of transportation and associated infrastructure create greater barriers associated with retrofit. The Punggol Digital District case study provides a clear example of these contrasts, in comparison with the Nava Nakorn case study. Specifically, the purpose built Punggol Digital District will be served by the Punggol Coast MRT, a bus interchange, and new bus stops, and is designed to be 'car lite', with shared car parks and vehicular access roads all located underground in order to free up the ground level for public-use, bicycles, and pedestrians. Conversely, the survey of Nava Nakorn residents indicated the majority used their own vehicle for the commute to work. The limited public transit options in Nava Nakorn were addressed by the designs of a transportation hub to better link the community while TOD was embraced as a planning principle by NNPC (Irvine et al., 2022a). Furthermore, high quality mass transit in Singapore currently is more seamlessly connected and equitably affordable than in Bangkok. While public bus systems in Bangkok are affordable, they can be slow and suffer from discomfort due to older technology. The BTS and MRT systems are expanding, but pricing equitability (e.g subsidies for target demographics as is done in Singapore) must be better addressed.

Khare et al. (2023) reported that access to high-quality transit services associated with TOD areas in India facilitated the transmission of Covid and not suprisingly, Covid negatively impacted public transit ridership. Although Khare et al. (2023) expressed doubt about the ability of crowd management measures to mitigate the rate of Covid infection, Tirachini & Cats (2020) suggested that travel apps might provide effective flow management, such as the one developed in Singapore that reported bus crowding information on a real-time basis. As noted, seamless public transit use in the BMA/BMR is hindered due to different operators and modes of transportation. Yet, Thailand's rapid shift to a cashless society, particularly driven by concerns over Covid, was remarkable (Septech et al., 2023), to the extent that over the course of less than a year most small stalls even in local wet markets accepted payment through QR code. This cashless transition in Thailand suggests a smarter payment system for public transit could be possible.

4.3 Smart Environment and green space comparison between Singapore and Bangkok

As with Smart Mobility, the challenges for BMA/BMR probably are greater to overcome than Singapore with respect to Smart Environment due to the historical lack of/fragmentation of green space. There are clear differences in the existing formally-established green space, as evidenced in the per capita area statistics, for Singapore (56 m^2 per capita) and Bangkok (3 m^2), although it is encouraging that the BMA has established plans for increasing green space and has showcased its vision through developments such as Benjakitti Park. Furthermore, both of the case studies emphasized the importance of green space for community wellbeing and sustainability.

Both Singapore and BMA/BMR experience a tropical climate with high temperatures and rainfall. Greater green space can help to mitigate urban heat island impact, but also, with appropriate design, is able to accommodate and manage the greater rainfall and runoff rates as compared to temperate climates. This ability to potentially mitigate impacts of higher temperatures and more frequent, intense rainfalls, afford an enhanced resilience to climate change. Furthermore, benefits of green space in reducing Covid infection and mortality have been reported, but the impact can be influenced by park design (e.g. size, connectedness, blue/green space, location of forest vs. open space, Ciupa & Suligowski, 2021;Yang et al., 2022). As such, further research is needed to consider how green space design can facilitate resilience to disruptive events such as Covid. Design visioning and consultation with community, as illustrated in the Nava Nakorn case study, can optimize the Smart Environment benefits through green space implementation.

4.4 Ways forward

Kumar et al. (2019) note that IoT already plays an important role in Smart City development and we believe that the applications will continue to expand. As we demonstrate here, IoT can help to assess the performance of green infrastructure and moving forward, further integration of IoT, Building Information Modeling (BIM), and environmental modeling will facilitate true digital twin approaches to project design, monitoring, and maintenance (e.g. Petschek et al., 2024).

An interesting similarity between the Punggol Digital District and Nava Nakorn case studies is that a digital hub or village is a focal point to help facilitate Smart City development. These digital hubs are seen as accessways to innovatively connect universities and private enterprise, providing an interactive incubator of collaborative benefit and certainly are consistent with addressing the barriers to upscaling Smart City initiatives noted in Section 4.1.

Finally, although we focus on two smart pillars here, Smart Environment and Smart Mobility, in fact the seven pillars are interconnected. As illustrated by both the Nava Nakorn and Punggol Digital District case studies, elements of Smart Environment, Smart Energy, Smart Mobility, Smart People, and Smart Governance are being considered collectively and not independently. ICT can support these interconnections, but ultimately, we believe the community and stakeholder vision needs to frame and inform the technology applications.

Based on our case studies of the broader Singapore and Bangkok context, as well as the more specific Punngol Digital District and Nava Nakorn case studies, it can be concluded that a Smart City design philosophy provides a rich diversity of opportunity to enhance sustainability, resilience, and wellbeing of a community with respect to future disruptions, including climate change and pandemics. Despite differences in planning and governance systems, endpoints of the Smart City visions in Singapore and Bangkok have some distinct similarities related to Smart Mobility and Smart Environment, specifically with respect to an efficient TOD-oriented public transit system and a diversity of green space opportunities that will help to increase urban resilience to disruptive events. Singapore clearly is further along the Smart City path than Bangkok and the path bearings may be site-specific, but we believe a more nuanced comparison shows that Bangkok has the potential to and is pursuing elements of Smart City programs in its aspiration to be a global city.

5. Declarations

Author Contributions

Conceptualization, K.N.I., F.L., A.S., A. Suwanarit, D.D.; methodology, K.N.I. F.L., A.S., A. Suwanarit, D.D., F.M.C.D., D.C.; software, D.C. K.N.I.; formal analysis, K.N.I., F.L., A.S., A. Suwanarit, D.D., F.M.C.D., D.C.; writing-original draft preparation, K.N.I., D.D., F.M.C.D.; writing-review and editing, K.N.I., D.D., F.M.C.D., F.L., A.S., A. Suwanarit, D.C.; visualizaition, F.L., A.S., K.N.I., F.M.C.D., D.D. All authors have read and agreed to the published version of the manuscript.

Human Subjects

All research procedures involving human participants were done in accordance with the ethical standards of the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Participation in the study was voluntary and informed consent was obtained for all research components that involved human participants, in accordance with standard ethical practice.

Use of Generative Artificial Intelligence (AI) and AI-Assisted Technologies:

No AI or AI-Assisted technologies were used in the writing or editing of this manuscript.

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