

Article

Developing a Smart and Sustainable Campus in Singapore

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Abstract: Singapore intends to become a “Smart Nation” through the use of smarter technologies and sustainable means to enhance the quality of life of its inhabitants. Universities are also increasingly seen as places of innovation of new smart and sustainable technologies, provincializing ideas and debates; serving as a testbed for local experimentation. Hence, to determine the status of developing Singapore universities as smart and sustainable campuses, this paper first discusses the role of Singapore’s Smart Nation initiative in relation to the development of smart and sustainable universities in Singapore. In particular, NTU’s development as a smart and sustainable campus. Secondly, a conceptual framework is developed to assess NTU as a smart and sustainable campus by understanding the prevailing dimensions of the smart city discourse. Through a detailed survey and ethnographic field study method conducted on NTU Campus, the study finds that the university has been rapidly deploying smart technologies to enhance students’ learning environment and university residents’ everyday quality of living through technology and sustainability initiatives. This paper contributes meaningfully to the development of smart campuses worldwide and brings an Asian university perspective to the existing research on smart and sustainable campuses.

Keywords: Smart Nation; smart cities; smart campus; sustainable campus; Singapore



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1. Introduction

Within the global city literature, the smart city discourse has been gradually gaining traction and popularity. While there are many definitions, interpretations [1] and developmental models [2] of a smart city, many cities are still devoting gargantuan amounts of resources to various urban areas, attempting to jump on the “bandwagon” of becoming a smart city [3]. Despite no “ideal” smart city model, a smart city can be categorised by the pervasive use and integration of Information and Communication Technologies (ICTs) within the lived environment to solve urban problems [1,3]. In a smart city, the quality of human capital is also important; the city inhabitants must have the technical know-how to drive the city’s innovation and development [4]. Hence, in order to effectively harness the ICT infrastructure and human capital, cities turn to the development of higher education institutions such as universities.

Universities are seen as incubating grounds to develop future technologies [1] and to build up the quality of human capital for a city’s development [5,6]. Coupled with the focus on building up skills in Science, Technology, Engineering and Mathematics (STEM) or programming, and developing a culture of innovation, universities can help to develop human potential, research and learning processes required in a smart city [7,8]. Furthermore, shifting away from solely knowledge acquisition towards a curriculum which prepares its students for the future (smarter) workforce helps to further hone the quality of human capital in the city [8]. Smart campus development enhances digital services in teaching resources, learning activities, environmental practices in the campus and overall quality of life for the campus residents [9]. As such, the development of universities as smart universities and campuses would be able to strengthen and propel a city’s (smart) development trajectory and agenda [7,9].

Min-Allah and Alrashed [10] argue that a smart campus with its smart physical and digital spaces and infrastructure acts like a small-scale smart city. Further, there has been a call for aligning smart campus development initiatives with the UN SDGs to address socioeconomic challenges faced by the world and enhance sustainability across cities, regions and countries [11]. Among the list of smart cities, Singapore is ranked consistently as one of the top global cities. Ranked amongst the top 10 in various smart city rankings, Singapore not only has plans to develop initiatives to strengthen its “Smart Nation” status, but also develop its universities as smart and sustainable campuses of the future. As many of the smart university initiatives are still in their infancy, there is a limited understanding on how cities or countries such as Singapore can effectively manage and develop a smart and sustainable university. Hence, to investigate this, this study intends to assess how Nanyang Technological University (NTU), an autonomous university in Singapore, is developing a smart and sustainable campus by broadly answering these questions:

1. To what extent is NTU implementing and adopting technologies, programmes and initiatives to enhance and create a smart and sustainable campus? and
2. What are the challenges and way forward to develop NTU as a smart(er) and sustainable campus?

To assess NTU as a smart and sustainable campus, the paper is structured as follows. Firstly, the paper will discuss the role of Singapore’s Smart Nation initiative in relation to the development of (smart) universities in Singapore. Secondly, by understanding the prevailing dimensions of the smart city discourse, a conceptual framework is developed to understand the potential components of smart universities. Lastly, through a field study conducted within NTU’s Yunnan Garden Campus, the paper will report and discuss the findings on the current status of the university as a smart and sustainable campus, highlight salient issues and discuss the way forward.

Smart Nation and Singapore Smart Universities

Recognising that there is no one model or definition of a smart city [3,12], Singapore launched the “Smart Nation” initiative in 2014 to guide the city-state towards the future of smart city development. Despite this, the city-state’s journey towards a technologically enabled future can be traced to Singapore’s first National IT Plan in 1986 [13]. Subsequently, plans to drive Singapore towards the digital age, such as the Intelligent Island: IT2000 [13] and the intelligent Nation 2015 [14], were launched to enhance the quality of life of its residents and boost Singapore’s economic competitiveness. These plans culminated with the inauguration of Singapore’s Smart Nation initiative which aims, broadly, to empower its residents to live “meaningful and fulfilled lives, enabled seamlessly by technology [and to] seize opportunities in the digital economy” [15] (p. 4). To drive and chart this transformation in Singapore, the city-state has developed various frameworks—one of which stresses on the nexus between academia, industry, and the government. This nexus focuses on the use of key infrastructure to drive economic growth, tackle national challenges and transform the urban landscape for greater liveability and sustainability [15]. As such, key infrastructures such as universities play a pivotal role in Singapore’s Smart Nation trajectory.

For a city to be “smart city ready”, it is important that its inhabitants are equipped with the right skills and knowledge to participate actively in a smart city [16]. Universities are institutions where these essential knowledge and skill transfers can occur to spur social and economic development and innovation in local economies [17,18]. Likewise, a university’s quality of education and research opportunities have been shown to develop sources of quality human capital [4,19]. The presence of universities also serves as an opportunity to draw, foster and retain human capital—resulting in a net “brain-gain” which helps to drive a city’s development [17,20]. Furthermore, with the human capital acquired, graduates will be part of an active (smart) community, collaboratively innovating solutions to solve urban problems to better the lives of the city’s inhabitants. For example, in Singapore Management University (SMU), a new undergraduate programme major in Smart-City Management and Technology was launched in 2017. Under this new SMU programme,

students' cross-disciplinary knowledge is strengthened to enable them to innovatively create solutions for urban challenges [21]. Likewise, SMU-X, an innovative pedagogical approach to learning, was launched to better prepare students for the changing economic landscapes [8]. All these programmes are in line with the core of Singapore's Smart Nation efforts—to empower its people to create change in the urban environment, and at large, the Smart Nation [15].

Universities do not just function as institutes that develop human capital but also centres of intensive Research and Development (R&D). A university's investment in R&D not only builds up the quality of human capital, but also provide positive externalities through technology transfer to the city's overall R&D [4]. Universities do so by coordinating and incubating future technologies with stakeholders which drive transformation in the urban environment and the city [22–25]. Test-bedding on a smaller scale also allows a more and more efficient development and testing process [26]. In NTU, the university and Volvo have collaboratively launched the world's first 12 m-long autonomous bus. This bus, test-bedded at the NTU Centre of Excellence for Testing and Research of Autonomous Vehicles, was set on full road trials in Singapore by 2019 [27]. This shows one of the ways in which the government (i.e., Land Transport Authority of Singapore) works in nexus with public and private stakeholders to drive future changes in Singapore's urban mobility landscape.

Henceforth, in tandem with Singapore's development towards a Smart Nation, several initiatives and specialised research centres (see Table 1) have been spearheaded by the six publicly funded Autonomous Universities (AUs) in Singapore.

Table 1. Singapore's six Autonomous Universities (AUs) and some of their initiatives driving towards Singapore's Smart Nation.

Singapore's AUs	Example Initiatives
Nanyang Technological University (NTU)	NTU Institute of Science and Technology for Humanity Smart Campus Initiative
National University of Singapore (NUS)	NUS Smart Nation Research Cluster NUS Centre for Research in Privacy Technologies
Singapore Management University (SMU)	SMU's Research in Smart Cities and Urban Management Launch of Smart-City Management and Technology Major (Undergraduate Programme)
Singapore University of Technology and Design (SUTD)	ST Engineering-SUTD Centre for Smart Systems Lee Kuan Yew Centre for Innovative Cities Launch of BEng (Hons) Telematics (Intelligent Transportation Systems Engineering)—Undergraduate Programme
Singapore Institute of Technology (SIT)	Collaboration with JTC on projects related to Smart Facilities Management and Operations (SIT in Punggol in 2023) Launch of E-textbooks
Singapore University of Social Sciences (SUSS)	Continuing Education and Training (CET) course on Information Security Challenges in Smart Computing

Source: Compiled by authors.

2. Conceptual Framework for Understanding Smart Universities

Several scholars have implemented measurement indicators [18,28] to assess smart cities through a list of rating systems. While indicators of smart cities can function as a tool to develop a conceptual understanding, it should not be used in its entirety. Each smart university is unique on its own [24], and just like a smart city, there is no one-size-fits-all model of a smart university. Furthermore, as Kitchin et al. [29] argue, “there is a politics to indicator and benchmark selection” (p. 18), and the selection of defined indicators might be biased. Likewise, recognising the diversity of places and spaces, there should not be one canonical example of an ideal “smartness” [2,30]. Therefore, a proposed conceptual framework, broadly based on [31] multidimensional components of a smart city, seeks to better understand the development of smart universities. We also seek to understand the

locally specific and provincializing elements of Smart Nation that is reflected through smart campus programmes.

The programmes launched as part of the university’s “smart” initiative can be segmented into the technological, human, institutional and environmental dimensions (see Figure 1). Though a programme might be targeted at a single dimension, it might draw on programmes from other dimensions to enhance its overall effectiveness. Underpinning all the four dimensions is a humanistic approach located at the heart of the framework. Just like how citizens are the core of smart city initiatives, this approach stresses the need to place the university’s key stakeholders, in particular its end-users, at the *core* of any smart university initiative. Prioritising a humanistic, bottom-up approach will therefore help us better assess how universities can move forward to become smart and sustainable.

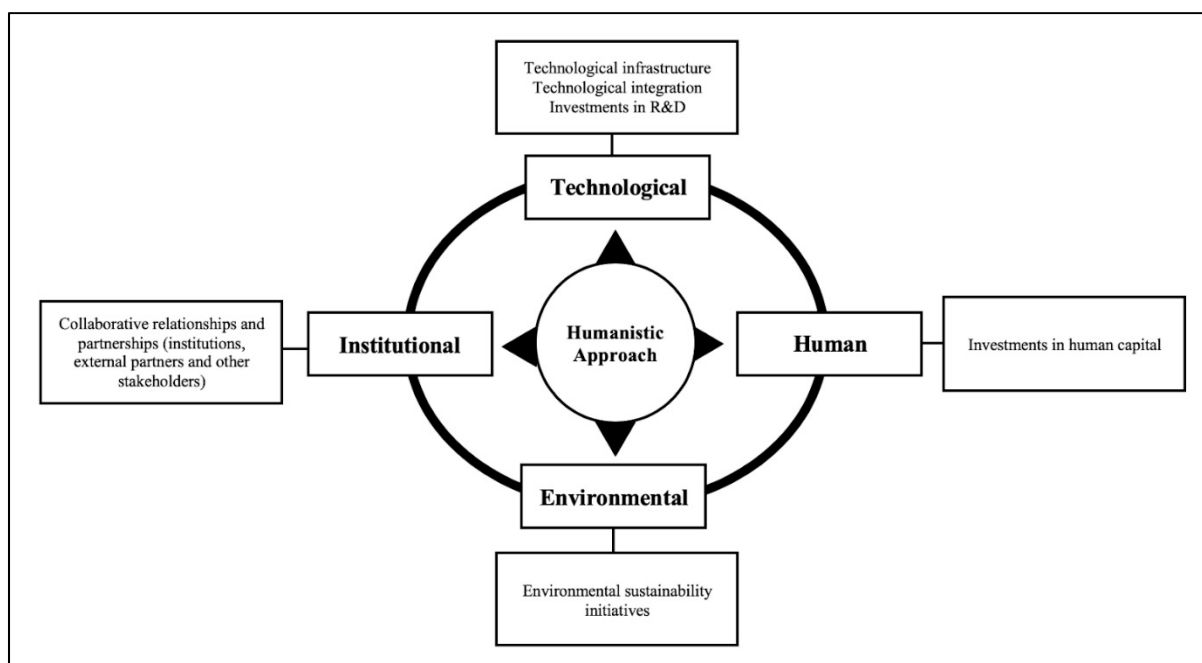


Figure 1. Proposed conceptual framework for understanding smart universities. Source: Authors’ developed framework.

2.1. Technological Dimension

A well-functioning technological infrastructure has been argued to be necessary for a smart city (Nam & Pardo, 2011) and, similarly, is one of the approaches taken in building smart universities [32]. This dimension is demonstrated through the incorporation and utilisation of technologies in various areas of the university campus. Examples include the use of smart, collaborative technologies in a university’s learning environments [32], mobility [24] and other physical infrastructure on the university campus [5]. As the use of technology can also be used to coordinate and integrate different subsections of a city [12], a smart campus should also be able to demonstrate a degree of integration between the services and amenities provided as well. One example of such technology usage and integration is the adoption of smart card technology in Washington University. This smart card gives students access to campus facilities and also functions as a stored-value card for services such as laundry [33].

Besides the implementation of technology, R&D can be construed as a crucial component within a smart university. As shown in both [34] research, investments in R&D are important because it drives innovation and helps in the effective deployment of technologies and technological infrastructure, and at large, helps to accelerate the growth of a smart city. Thus, a robust R&D infrastructure in a smart university is vital to not only its campus, but also to the city as well.

Technology might serve as a driver to boost competitiveness and transform cities into smart cities, and universities into smart universities. However, there should be a focus on fulfilling the needs of its inhabitants and no neglect of those who are not technologically savvy [12]. Technology in a smart city should also be used to empower and educate its people [3]. Thus, a user-centric focus should be at the forefront in every implementation of (smart) technologies in a smart university.

2.2. Human Dimension

The importance of human capital has been illustrated in various smart city discourses [31,34]. Thus, investments in human capital could help to drive the development of local and global economies. Gunasekara [35] and Neirotti et al. [34] also highlight that investments in human capital can enhance a city's capacity to learn and innovate, harnessing talents and driving the development of smart cities. Therefore, in the context of smart universities, the curriculum and programmes would need to prepare students for the challenges of the new digital economy. Lifelong learning is an important aspect associated with the development of human capital in relation to development of smart cities. Commitment towards lifelong learning not only increases the quality of human capital in a city, but also helps to enhance quality of life for everyone [36]. These new sources of quality human capital would thus be able to help a city to drive (smart) solutions towards urban development [31].

2.3. Institutional Dimension

In the context of smart cities, governments should foster and strengthen collaborative relationships with the residents, communities, businesses and even other smart cities to stimulate the smart city's continual innovation and progress [12,31,37]. It has been shown through an empirical study by Lee et al. [38] that a strong and clear leadership will help to drive engagement with a city's stakeholders. In smart universities, then, an effective leadership with policies to engage students, faculty and staff in its smart initiatives will thus help to drive towards a smart(er) university. In smart cities, giving the city's inhabitants access to information and data provides them the opportunity to make decisions, and provide and co-create innovative (smart) solutions to better their lives [31]. For example, in Singapore, a one-stop venue for a free and open data portal was set up in 2011, allowing anyone to have access to these datasets. The government intends to use the repository to help "unlock economic value, enable quality research and deepen public participation and engagement" [39] (p. 1). Smart universities could also provide similar opportunities and create an environment where students are given opportunities and are empowered to collaboratively innovate [32,40].

2.4. Environmental Dimension

Environmental sustainability is incorporated within the discourse of smart cities and smart universities. Although emphasis on environmental sustainability has not been consistent in smart cities globally, it is still largely a recurring domain in initiatives related to smart cities [34]. In recent times, an increased emphasis on climate change has been noted. These include low carbon, eco-cities and issues of environmental sustainability which are often amplified in recent smart city discourses [41]. Countless resources and environmental waste are used in the development of any city [41]. It has been reported that urban areas account for 75% of the world's energy consumption and 80% of greenhouse gas emissions [41], thus creating an urgent need for smart cities to innovate environmental solutions and focus on sustainability.

Universities, which are part of the same social-ecological landscape, are likewise influenced by a city's practices, and as such universities see the need to be part of this transformation [25]. The drive towards environmental sustainability is also recognised through the increase in the number of sustainability or sustainable development programmes embedded within a university's curriculum and vision [6]. Likewise, Ref. [42] have argued

that universities can serve as sustainability incubators. Students, faculty and staff can be empowered and guided to be active agents of change in environmental sustainability. They also demonstrate how components of sustainability education and research, sustainability operations as well as sustainability planning, administration and engagement can drive the sustainability ecosystem within the university. This is also seen in research [25] where effective collaboration on sustainability issues is able to drive development trajectories and innovation in the larger built environment.

3. Methods

NTU's main university campus, the 200-hectare Yunnan Garden Campus which houses most of the university's colleges, was chosen as a field site for this study. Firstly, information pertaining to the various smart and sustainable initiatives in NTU were collated through online news reports, university press releases and NTU promotional collaterals. A summary of NTU's smart and sustainable campus initiatives is shown in Table 2. Secondly, using this information, specific smart campus initiatives which have the potential for high student involvement were chosen—NTU Smart Learning Spaces, NTU Smart Pass Initiative, Mobile E-Payments and No Single-use Plastic Bag initiative.

Table 2. Nanyang Technological University (NTU), Singapore—Smart and Sustainable University Compilation of Some Notable Initiatives.

Dimensions	Components and Initiatives	Details
1. Technological	- Technological infrastructure	1. NTU Smart Pass
	- Technological integration	2. NTU Smart Learning Spaces
1. Technological	- Investment in R&D	3. Mobile E-payments
		4. Smart mobility:
		- NTU-BlueSG Flash Charging Shuttle
		- Autonomous Volvo electric buses
		- NAVIA, an autonomous electric vehicle which aims to provide a driverless shuttle service between NTU Campus and Clean Tech Park
		5. Internet-of-things (IoT):
		- IoT@NIE Living Lab: 4 IoT meteorological stations in the NIE
		- IoT@NIE Learning Lab, a physical learning space at NIE
		6. 3D Printing facilities—The Arc and The Hive
		7. Drone delivery of parcels
		8. NTU's humanoid robots
2. Human	- Investments in human capital	9. Smart retail—touch screen vending machines fitted with cash-free payment systems
		10. Smart locker—NIE library
		11. Smart attendance taking system (on trial)
		1. NTU Institute of Science and Technology for Humanity
		2. Lifelong learning for alumni (professional development courses—Centre for Continuing Education)
		3. Bachelor of Science in Data Science and Artificial Intelligence (new programme from AY18/19 onward)
		4. Strategic Centre for Research in Privacy-Preserving Technologies & Systems (SCRIPTS)—research centres to design and develop privacy technologies and train skilled manpower

Table 2. Cont.

Dimensions	Components and Initiatives	Details
3. Institutional	- Collaborative relationships and partnerships - Engagement opportunities	1. NTU–Cleantech Park partnership
		2. NTU–Volvo–Land Transport Authority (LTA) partnership
		3. SMRT–NTU Smart Urban Rail Corporate Laboratory
		4. Delta–NTU Corporate Laboratory for Cyber-Physical Systems
		5. Surbana Jurong–NTU Corporate Lab at NTU
		6. NTU EcoCampus’ industry (private–public) collaboration in its green building systems, smart grids, urban mobility, energy information analytics and user behaviour systems
4. Environmental	- Environmental sustainability initiatives	1. EcoCampus initiative—campus-wide initiative not to use single-use plastic bags
		2. oneNTU initiative: ECHO
		3. FoodBank@NTU bins
		4. Dedicated e-waste collection (Starhub RENEW E-Waste bins)
		5. Recycling bins located throughout campus
		6. Green Mark Platinum-certified buildings in NTU
		7. Energy-efficient lights with motion sensors—The Arc
		8. Natural foliage incorporated to reduce the reliance on artificial cooling devices—The Arc
		9. Passive displacement ventilation system—sports hall (The Wave)
		10. Pre-fabricated Pre-finished Volumetric (PPVC) construction—North Hill residences
		11. Natural ventilation—The Hive, The Arc and Academic Block North
		12. Solar power-generating windows—South Spine
		13. Solar-equipped lights on roads in NTU
		14. NTU Sustainable Earth office

Source: Compiled by authors.

Thereafter, to explore the ground-up perspectives of these initiatives, a survey questionnaire, comprising a series of open- and close-ended questions, was distributed to NTU’s undergraduate population. The survey questionnaire helps to explore people’s perception, attitudes, experiences, behaviours and spatial interactions [43] within the campus. After a pilot questionnaire was conducted amongst five NTU undergraduates from different colleges, the questionnaire was administered online via Google Forms through snowball sampling. A total of 156 valid responses from NTU undergraduates of varying colleges were obtained.

To corroborate and validate the findings in the survey questionnaire, on-site field observations with photos were taken [44]. Field observation was carried out by recording the observed phenomenon, followed by subsequent analyses and interpretation [45]. However, in order to direct the observations specifically, photos were also captured on site. Photos are able to convey a certain truth about a place, showing the possible realities on the ground directly to the viewer [46] and also to “look with intention” [47] (p. 181). The photos captured also open up opportunities for deeper analyses by capturing and questioning details which might not be uncovered solely through observation [48].

4. Results and Discussion

4.1. Results

In this section, we deliberate on the results that we collected from the surveys conducted in the NTU Campus with students and other stakeholders in relation to technological aspects in relation to various smart and sustainable awarenesses such as availability and use of smart learning spaces, smart passes, use and extent of e-payment systems and no single use of plastics in the university campus. Below, we show the results from our data in table form and with correlation results between various smart and sustainable

initiatives and campus living experiences (see Tables 3–9). This is then followed by a detailed discussion in the next sub-section.

Awareness of Initiatives

Table 3. Awareness of NTU Smart and Sustainable Campus Initiatives.

		Aware	Not Aware
Initiatives	Smart Learning Space	139 (89.1%)	17 (10.9%)
	NTU Smart Pass	108 (69.2%)	48 (30.8%)
	Mobile E-Payments	150 (96.2%)	6 (3.8%)
	No Single-use Plastic	145 (92.9%)	11 (7.1%)
	Mean (<i>M</i>)	135.5 (86.85%)	20.5 (13.15%)
Standard Deviation (<i>SD</i>)		18.9 (12.12%)	18.9 (12.12%)

Frequency of Use & Smart Learning Spaces

Table 4. Use of Smart Learning Spaces on the NTU Campus per week.

		Never	1 to 2 Times	3 to 4 Times	More than 4 Times	Median (<i>Mdn</i>)
College	College of Engineering	8 (14.3%)	18 (26.5%)	9 (47.4%)	4 (30.8%)	
	College of Science	10 (17.9%)	13 (19.1%)	1 (5.3%)	0 (0.0%)	
	Nanyang Business School	5 (8.9%)	19 (27.9%)	5 (26.3%)	2 (15.4%)	
	College of Humanities, Arts, & Social Sciences	8 (14.3%)	4 (5.9%)	1 (5.3%)	3 (23.1%)	
	National Institute of Education	22 (39.3%)	10 (14.7%)	2 (10.5%)	4 (30.8%)	
	Other Faculties	3 (5.4%)	4 (5.9%)	1 (5.3%)	0 (0.0%)	
Total		56 (35.9%)	68 (43.6%)	19 (12.2%)	13 (8.3%)	1 to 2 times

NTU Smart Pass

Table 5. Use of NTU Smart Pass Functions per week.

		Never	1 to 2 Times	3 to 4 Times	More than 4 Times	Median (<i>Mdn</i>)
Functions	Cashless Payments	99 (63.5%)	22 (14.7%)	17 (10.9%)	17 (10.9%)	Never
	Security Access	48 (30.8%)	57 (36.5%)	22 (14.1%)	29 (18.6%)	1 to 2 times
	Campus Services	38 (24.4%)	72 (46.2%)	28 (17.9%)	18 (11.5%)	1 to 2 times
	Off-campus Services	68 (43.6%)	35 (22.4%)	26 (16.7%)	27 (17.3%)	1 to 2 times
Mean (<i>M</i>)		63.25	46.50	23.25	22.75	
Standard Deviation (<i>SD</i>)		22.90	22.31	4.86	6.13	

Mobile E-Payments

Table 6. Use of Mobile E-Payments per week.

	Never	1 to 2 Times	3 to 4 Times	More than 4 Times	Median (<i>Mdn</i>)
Mobile E-Payments	34 (21.8%)	34 (21.8%)	24 (15.4%)	64 (41%)	3 to 4 times

No Single-use Plastic Initiative

Table 7. Purchase of Single-use Plastic on NTU Campus.

	Never	1 to 2 Times	3 to 4 Times	More than 4 Times	Median (Mdn)
Purchase of Single-use Plastic	113 (72.4%)	37 (23.7%)	3 (1.9%)	3 (1.9%)	Never

Support for Smart and Sustainable Campus Initiative

Table 8. Support for NTU Smart and Sustainable Campus Initiative.

		1	2	3	4	5	Median (Mdn)
Initiatives	Smart Campus	2 (1.3%)	3 (1.9%)	23 (14.7%)	79 (50.8%)	49 (31.4%)	2
	Sustainable Campus	2 (1.3 %)	1 (0.6%)	23 (14.7%)	77 (49.4%)	53 (34.0%)	2
Mean Count (M)		2	2	23	78	51	
Standard Deviation (SD)		0.00	1.41	0	1.41	2.83	

Note: On a Likert scale, 1—Not Supportive to 5—Supportive.

Correlation Between Initiative Use and Campus Life Experience

Table 9. Spearman correlation between the initiative and the respondents' campus life experience.

	Campus Life Experience	
Frequency of initiative use	Smart Learning Space	0.400
	NTU Smart Pass	0.618
	Mobile E-Payments	0.782
	No Single-use Plastic (does not purchase)	0.250

$N = 156, p < 0.001$.

4.2. Discussion

4.2.1. Smart Learning Spaces

Smart Learning Spaces (SLs) are learning environments enabled with (smart) technologies, which aim to support a more student-centred approach the learning. These spaces, located within the academic complexes of NTU, can be equipped with technologies such as IoT-supported projection systems, interactive technologies and sensor systems which can enhance the physical learning environment. Working laboratories with state-of-the-art smart technologies are also available on campus for niche programmes such as mechanical and aerospace engineering. Although there are multiple SLs located campus-wide, there are two specialised smart learning hubs—The Hive and The Arc—located within the NTU academic complex. In these learning hubs, all learning spaces (e.g., tutorial rooms and lecture theatres) are equipped with baseline (smart) technologies such as multiple projection systems and smart whiteboards. For instance, in The Arc, all tutorial rooms are equipped with the SOLSTICE projection system (Figure 2) which enables students to project their smart devices or computers to the multiple projection system within the room (see Table 4). Particularly, this form of smart technology supports student-centred learning pedagogies within the classroom (Figure 3).

While the research has shown that the majority of the respondents (64.1%) use these SLs, most of the respondents only use these spaces one to two times per week. Furthermore, a sizeable minority (35.9%) have reported that they do not use any SL. Even within the majority that reported a use of SLs, infrequent and inconsistent frequency of use have been noted across colleges. Providing an SL as a learning environment does not equate to higher usage of such spaces, rather, other factors also play a part in determining the

students' usage of SLs. Factors such as instructor/student readiness, nature of modules, teaching pedagogies and the campus-wide availability of technology can also impact the use of SLs. Likewise, other academic complexes might not be equipped with SLs, and some SLs such as the NTU's Singapore Centre for 3D Printing are only utilised by a select group of students. Hence, not all students would be able to utilise these spaces.

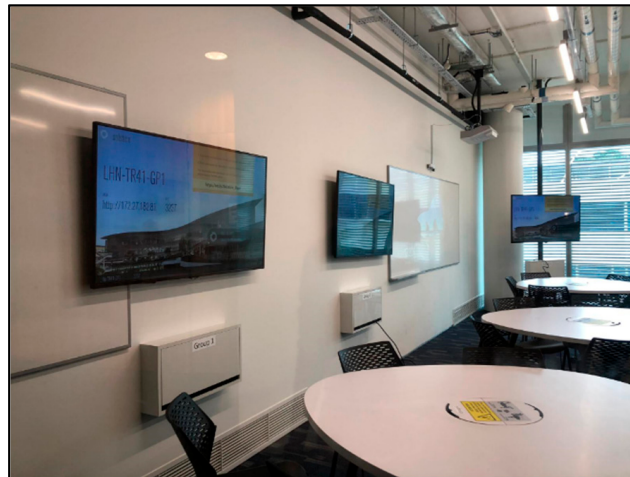


Figure 2. A tutorial room at The Arc equipped with the SOLSTICE system. Students are able to project the screens of their smart devices or laptops wirelessly.

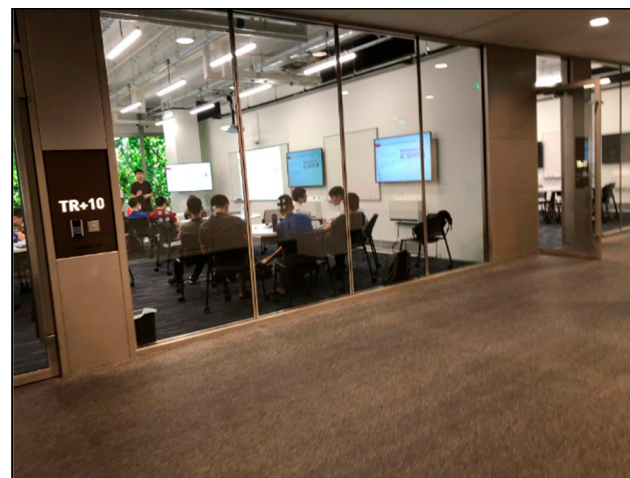


Figure 3. Ongoing tutorial session at The Arc. The presenter uses the SOLSTICE system to showcase a presentation.

4.2.2. NTU Smart Pass and Mobile E-Payments

The NTU Smart Pass is an all-in-one multipurpose contactless card that serves multiple uses. The pass can be used for public transportation, registration of various on-campus services, gaining access to secure facilities/rooms, paying of printing services, borrowing books and audio-visual materials and as an identification document. On top of these functions, the NTU Smart Pass also incorporates cash-free functions (e.g., NETS FlashPay) for purchases within and out of the NTU Campus. Another cashless payment solution available on campus is the Mobile E-Payment services (e.g., NETS QR Code functions and PayLah) which are enabled at most retail stores island-wide. Fieldwork observations carried out at NIE Canteen (Figure 4) showed that the mobile e-payment option is a popular choice as a mode of making payments among students. Similarly, the majority of the respondents have indicated that mobile e-payment is a frequent choice of payment (78.2%) on campus,

using it three to four times per week. Compared to the NTU Smart Pass, only 36.5% of the respondents utilise the cashless payment option. One key issue is that a limited number of students were using the NTU Smart Pass to make payments. As both are modes of smart payments, this could be possibly due to the overlap of payment functions of the NTU Smart Pass and mobile e-payments. It remains much more convenient to make payments through mobile e-payments that are directly linked to the user's bank account and as such payments are accepted island-wide. On the other hand, the need to top up the value of the NTU Smart Pass is an additional step that students need to perform in order to make payments. Henceforth, the mobile e-payment was a more well-received mode of smart payment as compared to the NTU Smart Pass.



Figure 4. A student making mobile e-payments using the NETS mobile application in NIE Canteen.

While the majority of the respondents have indicated that both the NTU Smart Pass and mobile e-payments have been beneficial to their campus life experience, there were some issues highlighted which could explain the frequency of use of these two initiatives. The importance of ensuring the sustainability of the smart initiatives is a common recurring theme amongst both initiatives—underlying problems and issues should be teased out so that they can be used effectively by the end-users. Respondents have highlighted issues such as the failure/non-existence of basic technological infrastructure that undermines the use of smart technologies, especially for the smart pass use. For example, some respondents have explained that older buildings do not have card access readers installed, there are faulty card readers and some food outlets still fail to accept mobile/NTU Smart Pass payments.

4.2.3. No Single-Use Plastic Bag Initiative

As part of NTU's goal to also be a sustainable campus, free single-use plastic bags have not been issued at any retail and food outlets within NTU from October 2018. Instead, all single-use plastic bags are charged at SGD 0.20 upon request (Figure 5). Of the respondents, 72.4% have shown their support for not purchasing any single-use plastic bags on campus since the initiative started. Within the few (27.6%) who chose to purchase these single-use plastic bags, 23.8% of the respondents have purchased them on up to two occasions per week while only a handful of respondents (3.8%) purchased them on more than two occasions per week. This could be accounted for by situations where students make unplanned visits to retail outlets and do not have any reusable bags to store their bulky purchases. Nonetheless, the data collected generally show the effectiveness of the initiative in banning the usage of single-use plastic bags.

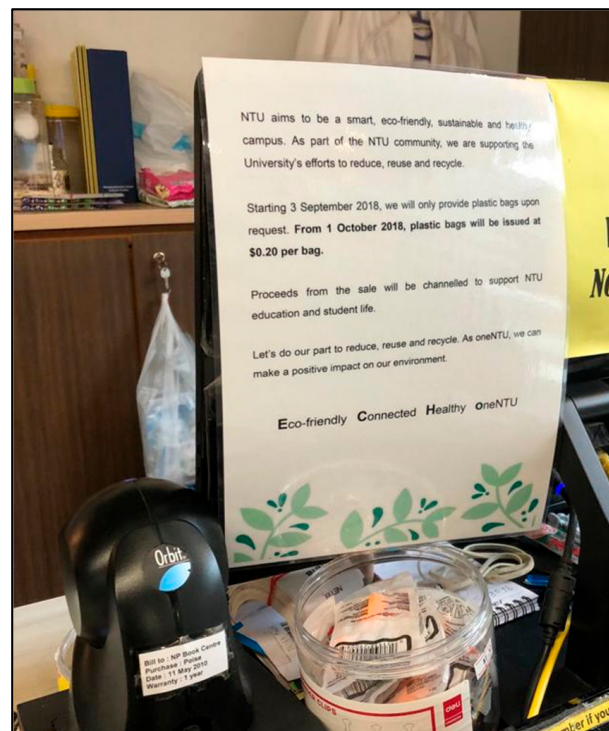


Figure 5. No Single-use Plastic Initiative: Notice of SGD 0.20 charge for the request of plastic bags in a bookshop at the North Spine academic complex.

Although the initiative has garnered support from the student population, there are a few challenges associated with this initiative and, at large, environmental sustainability. Many respondents have highlighted the need to develop sustainability with respect to other eco-friendly practices such as the reduction in general single-use plastic use instead of just plastic bags. One respondent stressed this concern, expressing that:

“More can be done [on environmental sustainability] though. A lot of single-use plastics are still used in the canteens and food courts. What’s the use of eliminating plastic bags only”?

Similarly, fieldwork observations conducted on-site showed that NTU’s move towards reducing single-use plastics is inconsistent. Fast food chains within the North Spine academic complex have either stopped or reduced the provision of plastic straws. When these initiatives are not consistent campus-wide, it might stifle efforts for the university to become an all-round smart and sustainable campus. In its effort to make NTU a smart and sustainable campus, the university Sustainability Office envisions achieving a carbon neutral campus by 2035 with 100% smart green buildings, clean energy vehicles in the campus and powering the campus through solar energy technology.

4.2.4. Moving Forward as a Smart and Sustainable Campus

Generally, initiatives supporting NTU’s vision towards a smart and sustainable campus have been well-received by the respondents. However, moving forward, the university can look into several areas to enhance, and to further develop, its initiatives to strengthen NTU as a smart and sustainable campus.

Incentivising Initiatives

Incentivisation of initiatives can be adopted by the university to reach out to more users. Although the respondents were aware of the university’s efforts to become more smart and sustainable, it is also important that these initiatives are effectively utilised. Incentivisation has been successful in adopting both the mobile e-payment and the no

single-use plastic bags initiatives. Both initiatives received the highest frequency of use (no single-use plastic bags, $Mdn = 0$; mobile e-payments, $Mdn = 3$ to 4 times per week) as compared to the other initiatives. During a promotional period in mid-2018, utilising the NETS QR (a form of mobile e-payment) for canteen purchases provided an incentive of SGD 0.50 per purchase. Since the end of this promotional period, other mobile e-payments have also targeted incentivisation (see Figure 6). Corresponding to incentivisation, a de-incentivisation strategy was utilised targeting the use of single-use plastic bags—SGD 0.20 is charged per single-use plastic bag purchased on campus. Fieldwork observations in NTU have likewise shown the pervasiveness of this initiative to reduce single-use plastic bag usage. Notices of the SGD 0.20 charge for the request of plastic bags was evident in most food and retail outlets on campus (an example, in Figure 5). Overall, the two initiatives which utilised (de-)incentivisation strategies received the highest average frequency of use. Incentivisation does not only encourage students' use for the incentivisation or promotional period, but more importantly, creates a habit, which pushes for the sustained use of the product.

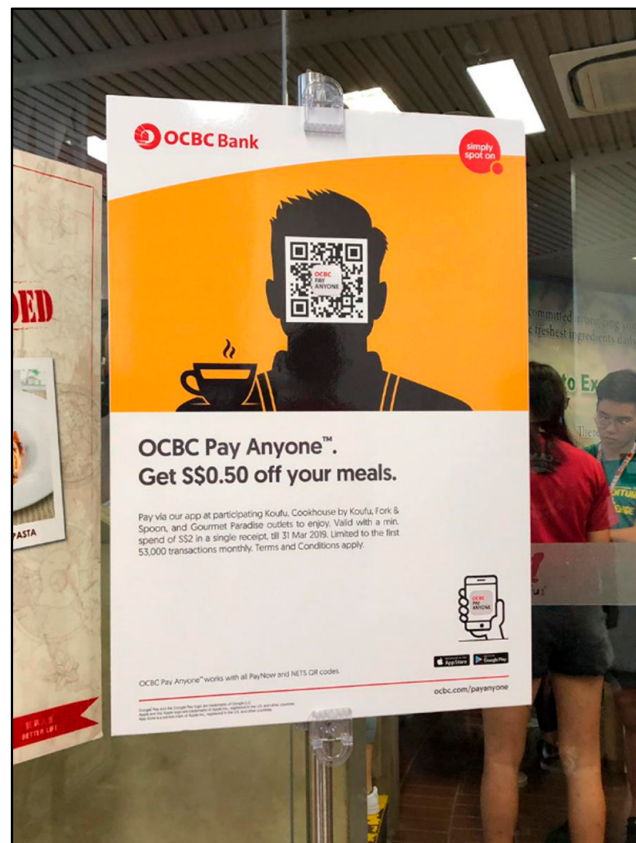


Figure 6. OCBC Bank's mobile e-payment promotion poster located at KouFu Foodcourt at the South Spine academic complex. Users are incentivised with SGD 0.50 with the use of the mobile e-payment.

Perceived Usefulness of Initiatives

Besides inculcating the habits of use through incentivisation, it is also important that the initiative must also be seen as beneficial to the end-users. Amongst the initiatives surveyed, there is a significant positive correlation between the respondents' use of the initiatives and the enhancement of campus life experience. When respondents perceive that an initiative enhances their campus life, the frequency of use will increase. The respondents' open-ended responses have also cited reasons related to convenience and the enhancement of learning when it comes to the implementation of smart initiatives. One respondent highlighted:

“The facilities [such as] ‘smarter learning’ is not very useful at its core. Will be better to think about how much actual value it will add to student’s learning rather than the value the school think it has [sic]”.

Likewise, another respondent expressed:

“I think the school really needs to find out what are the basic stuff that isn’t being done rather than keep on implementing new ‘smart’ stuff that doesn’t really help or affect students [sic]”.

In particular, through the field observations at NTU’s Prime Supermarket, students’ receptiveness to smarter ways of making payments may be varied. Patrons to the supermarket were observed utilise the manned counters more vis-à-vis the self-service kiosk (see Figure 7). Although patrons to the supermarket are provided with the means to initiate digital self-service payments, some will not be receptive towards such changes. Hence, there is also a need to shift the users’ mentality to accept these new technologies. Providers should also ensure the technological infrastructure is robust, and be able provide a seamless, uninterrupted self-service checkout experience. Essentially, students must see that there is a form of value addition to their campus life, which will propel them to use the smart initiatives launched on campus.



Figure 7. Students in NTU Prime Supermarket queuing to make purchases from the manned counter (right) vis-à-vis self-service kiosks (left). More people were observed to be queuing for the manned counter.

On the other hand, in relation to the sustainability initiatives, respondents have largely highlighted the importance of creating an awareness of and education of the importance of sustainability to push for greater use. One respondent particularly highlighted:

“EcoCampus initiatives [should create] an inclusive culture of care for the environment. . . [where students are] educated through experience of things other than academics [sic]”.

For sustainability-related initiatives, it is not just about pushing for the awareness of the presence of the initiative, but for the awareness of the *importance* of practising sustainability. Once students have a clear idea on the importance of cultivating sustainable practices, they will be more inclined to be a part of the sustainability initiatives introduced.

(Active) Campus Involvement

One of the prominent concerns on students' minds is the ability to be actively involved in the improvement of the existing smart and sustainable initiatives and to suggest ideas for the future. Notably, respondents have listed multiple ideas and suggestions that can improve the current initiatives and spearhead new initiatives. They have shown to have knowledge of other potential environmental sustainability and smart initiatives that can be introduced or improved in NTU. However, there are limited opportunities for students to be involved in the feedback and improvement of initiatives. As a humanistic approach is largely emphasised as an essential component in a smart and sustainable campus, it is important that the end-user (i.e., student) is placed at the centre of the initiatives. Understandably, there are already opportunities set out by the university to garner student feedback, however, these might be limited to the annual student experience survey or feedback through the students' union body. To encourage an *active* involvement, open and regular feedback channels should reach out to the general student population and made readily available so that any student can do their part in improving and suggesting initiatives. One respondent particularly highlighted:

“Be more in touch with student sentiment beyond conducting surveys to know what students actually want”.

Every student in a university should be seen as an agent of change and a (smart) student. Students should be readily able to play their part to exercise their eco/smart-citizenship in innovating new smart and sustainable initiatives, and providing feedback to enhance these initiatives.

Building Greater Awareness

Although the survey findings demonstrate that undergraduates have an awareness of NTU's smart and sustainable initiatives, there is still a need to push for greater awareness of the smart and sustainable campus initiatives. This can be carried out through enhancing the marketing strategies that are adopted to promote the initiatives. A total of 71.2% of the respondents expressed their uncertainty (responses that were NIL, NA or unsure) about knowledge of other NTU Smart and EcoCampus initiatives. A total of nine respondents directly or partly expressed the need for greater awareness for NTU to move forward in its Smart and EcoCampus initiatives. The need to build greater awareness is important for students to engage in the usage of smart technologies and exercise their smart- and eco-citizenship. Only with greater awareness can the student body provide valuable feedback to improve existing initiatives that are currently in place.

5. Conclusions

This preliminary study helps us understand the current status of NTU in its development towards a smarter and sustainable campus in Singapore. However, to delve deeper, several future research directions are proposed. Firstly, the evaluation of individual smart and sustainable initiatives. This research gave an overview of four selected initiatives in NTU, however, some issues surrounding them are unique. Thus, future research with an in-depth evaluation of individual initiatives might be able to help us better understand how they can benefit the users and strengthen the university's position as a smart and sustainable campus. Further, future research can also look at extending the Singapore experience to a larger comparative study with other universities across the world.

Secondly, the evaluation of different stakeholders with respect to the initiatives. Although undergraduates are a sizeable stakeholder of the university's population, postgraduates, faculty members and staff are also important. Additionally, with an emphasis on a humanistic, user-centric approach, understanding the needs of these other stakeholders will help to further enhance the initiatives to better serve all inhabitants within the campus ecosystem. This will facilitate NTU's enhancement as a smart and sustainable campus.

Lastly, the need to conduct comparative studies with other autonomous universities in Singapore. Autonomous universities in Singapore, such as SMU, have several initiatives to support Singapore's Smart Nation vision. A comparative study with other autonomous universities would help governing bodies of universities and the state to better focus policy-level initiatives to elevate the status of smart and sustainable university campuses in Singapore.

Ultimately, incorporating programmes supporting the four dimensions can assist a university to become smarter and more sustainable. From our current research, we also found that the campus itself also serves as an incubation ground to train and equip students with technological know-how, skills and knowledge. Eventually, this development of quality human capital would enable students, and graduates, to be part of an even larger smart ecosystem, exercising their smart-citizenship in the Smart Nation. A city's inhabitants are often placed at the centre of the various smart city discourses, thus, in a smart and sustainable university, it is important that a humanistic, user-centric approach should also be taken in any implementation of any initiatives. Understanding the implemented smart and sustainable initiatives from the ground up will allow the university to better innovate and strengthen these initiatives for the benefit of the university's population. With that, it would help to further develop and cement NTU's position to become a smarter and more sustainable campus in Singapore.

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