The Importance of Digital Tools in a Nature-based Climate Adaptation Program in Malaysia: The Case of Penang Island

Sofia R.M.B. Castelo, Think City. PhD Candidate, Instituto Superior Técnico.
sofia.castelo@thinkcity.com.my
+60147459490
Level 1, No 21-35
UAB Building, Gat Lebuh China
10300 Georgetown, Pulau Pinang
Malaysia
Miguel Amado, Professor, CERIS, Instituto Superior Técnico.
Melissa Sivaraj, Think City.

1. Introduction

The *Nature-based Climate Adaptation Program for the Urban Areas of Penang Island* (PNBCAP) was initiated to address the main climate impacts expected for Malaysia. The country's location is particularly vulnerable, as Southeast Asia is one of the three regions in the world which will be hardest hit by climate change[1]; the main impacts in Malaysia will be increasing temperatures, an increase in extreme weather events, and sea level rise.

Urban heat is of particular concern. Even though higher latitudes will experience greater warming, tropical locations will be the first to experience historically unprecedented climates[2]. A recent study has identified that several cities around the globe, including Kuala Lumpur, will shift outside the covered climate domain by 2050[3]. This means these cities will have a climate by 2050 that does not exist in any major city in the world at present. Malaysia has an equatorial climate, characterized by being hot and humid, with temperatures already near extreme in terms of public health impacts. Even minor temperature changes can significantly increase heat stress. Urban areas are particularly vulnerable, due to the urban heat island (UHI) effect and the concentration of population. As the Malaysian population will be mostly urbanized by 2050, severe impacts on public health in terms of heat stress and heat stroke are to be expected. Climate change is a threat to public health[4], affecting people across their life span, with the consequences of rising temperatures and extreme weather events having immediate health consequences.[5] [6] [7] The most vulnerable groups of society, such as the elderly, outdoor workers and the poorest (who cannot afford air-conditioned accommodation and transportation) will be particularly exposed. Public

[1] Masson-Delmotte, Valérie, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani et al. "Special Report on Global Warming of 1.5 C." *Intergovernmental Panel on Climate Change* (2018).
[2] Mora, Camilo, Abby G. Frazier, Ryan J. Longman, Rachel S. Dacks, Maya M. Walton, Eric J. Tong, Joseph J. Sanchez et al. "The Projected Timing of Climate Departure from Recent Variability." *Nature* 502, no. 7470 (2013): 183-187.
[3] Bastin, Jean-Francois, Emily Clark, Thomas Elliott, Simon Hart, Johan Van Den Hoogen, Iris Hordijk, Haozhi Ma et al. "Understanding Climate Change from a Global Analysis of City Analogues." *PLOS ONE* 14, no. 7 (2019): e0217592.
[4] Watts, N., M. Amann, N. Arnell, S. Ayeb-Karlsson, K. Belesova, and M. Boykoff. "The Lancet Countdown on Health and Climate Change: Ensuring that the Health of a Child Born Today is Not Defined by a Changing Climate." *The Lancet* 394 (2019): 2932596-6.
[5] Watts, Nick, W. Neil Adger, Paolo Agnolucci, Jason Blackstock, Peter Byass, Wenjia Cai, Sarah Chaytor et al. "Health and Climate Change: Policy Responses to Protect Public Health." *The Lancet* 386, no. 10006 (2015): 1861-1914.
[6] Watts, Nick, Markus Amann, Nigel Arnell, Sonja Ayeb-Karlsson, Kristine Belesova, Maxwell Boykoff, Peter Byass et al. "The 2019 Report of The Lancet Countdown on Health and Climate Change: Ensuring that the Health of a Child Born Today is Not Defined by a Changing Climate." *The Lancet* 394, no. 10211 (2019): 1836-1878.
[7] Beggs, Paul J., Ying Zhang, Hilary Bambrick, Helen L. Berry, Martina K. Linnenluecke, Stefan Trueck, Peng Bi et al. "The 2019 Report of the MJA–Lancet Countdown on Health and Climate Change: A Turbulent Year with Mixed Progress." *Medical Journal of Australia* 211, no. 11 (2019): 490-491.

hospitals in Malaysia do not identify heat stress or heat stroke which makes mapping the impact in terms of public health in the country highly challenging.

Flooding due to changes in rainfall patterns is also a major climate impact already unfolding. Rainfall has been increasing and is predicted to increase further for all of Peninsular Malaysia.[8] In November 2017, Penang was hit by its worst recorded floods, with seven lives lost and half of the urban areas submerged. A total of 159 areas reported being affected by floods, 68 of which had never previously flooded.[9] Substantial losses, estimated at between RM200 million and RM300 million (~USD 48 to 72 million), were reported in the manufacturing sector.[10] Data from the Department of Water and Irrigation shows that the average annual rainfall from 2010 to 2018 has seen an unusually high increase of 29.6% above projections.[8]

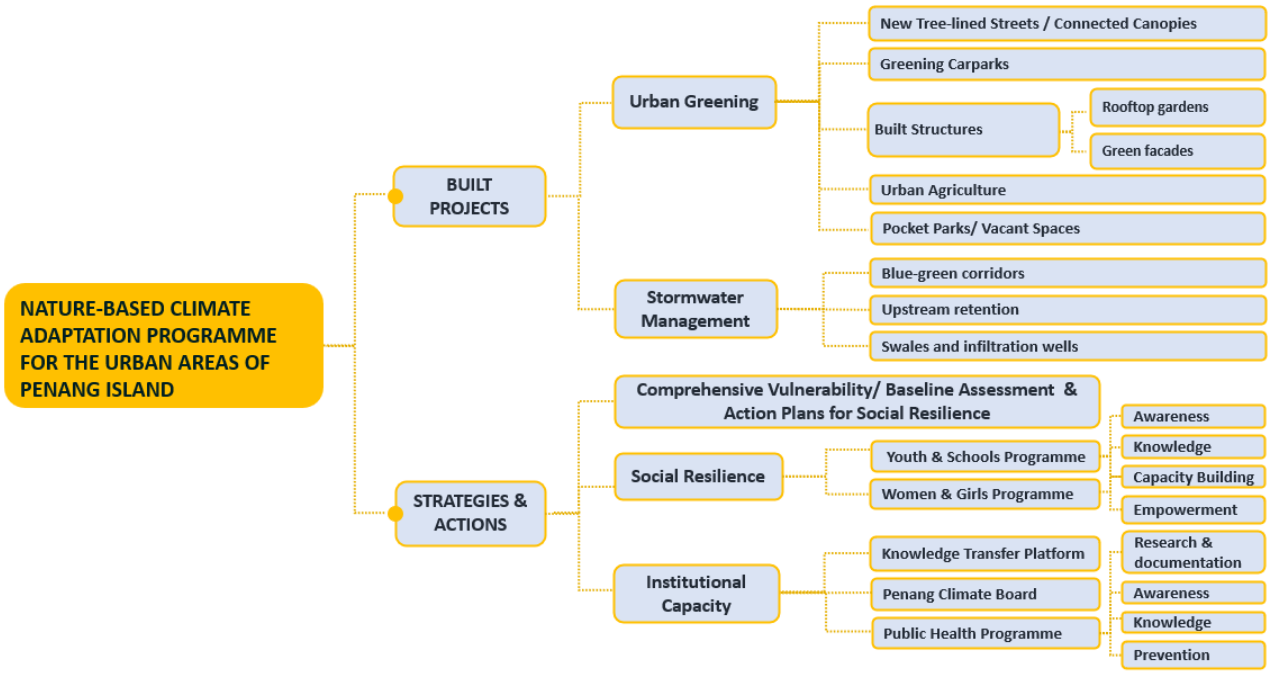

Image 1. PNBCAP components and sub-components.

Although the focus of the PNBCAP is on physical impacts, the program also addresses social resilience (with a focus on vulnerable communities), and reinforcement of institutional capacity.

[8] Ministry of Energy, Science, Technology, Environment & Climate Change (MESTECC). "Malaysia's Third National Communication and Second Biennial Update Report to the UNFCCC." *MESTECC Publication* (2018).
[9] Penang Institute. 2019. "Penang Economic and Development Report 2017/2018". Penang Economic and Development Report. George Town: Penang Institute. https://penanginstitute.org/programmes/socioeconomics-and-statistics-programme/penang-economic-and-development-report-2017-2018/.
[10] "1,000 Companies Lose RM300mil to Penang Floods". 2017. *The Star*. https://www.thestar.com.my/business/business-news/2017/11/10/1000-companies-lose-rm300mil-to-penang-floods.

2. The potential of digital tools for climate adaptation

Toolmaking is considered to be one of the main distinctive evolutionary traits of humanity, integral to our interaction with the environment[11]. The digital age allowed for an unprecedented expansion of variety of tools, particularly of the knowledge/epistemological type[12]. Digital tools have become indispensable for urban management, as the example of management of traffic lights illustrates. Digitization has also become a key instrument for promoting sustainable development and strengthening urban resilience.

In terms of climate adaptation, digital tools are most useful in four main areas: a) Assessment of climate impacts, b) Monitoring and evaluation (M&E) of strategies, d) Disaster risk reduction (DRR) and c) Knowledge transfer and replication of strategies.

The use of digital technology as a communication vehicle for raising awareness is, in itself, a tool for strengthening the involvement of the population in the process. Inclusion in dealing with climate change requires the involvement of all age and social groups in different societies. In what concerns the need to transmit procedures, inform the population and discuss solutions, digital tools substantially improve efficiency, allowing for accelerated responses in moments of crisis. In this approach framework, an impact organization such as Think City adopts technology to assist in designing and establishing: collaborations and partnerships; reinforcement of resilience and adaptation; identification of the main strategies for investing in the diversification of energy sources; mapping impacts of strategies on the field. The use of digital tools seeks to increase efficiency and maximize impacts through the diverse digital platforms and in the implementation of different programs aimed at climate adaptation.

Climate change can be a complex problem in the framing and design of the response[13], requiring that other types of knowledge and approaches are needed to improve results and to give a new way of action[14] supported by easy-to-use digital tools and user-friendly viewing environments[15]. In this context, the use of digital tools for climate adaptation projects, facilitating support to local governments and the impacted communities, must have a robust website as a communications platform[16], and one or more resource sites focused on informing and teaching the importance of knowledge and response to climate change.

When a Nature-based Solutions (NbS) approach is adopted for climate adaptation, new issues arise. One of the main challenges identified for NbS is the difficulty of precise measurement of its efficiency[17]. Digital tools can address this challenge while also improving transparency and accountability, in what has been designated *Internet of Nature (IoN)*, defined as *urban ecosystem components and interrelation dynamics described and represented through digital technologies*

[11] Heidegger, Martin. “The Question Concerning Technology.” Essay. In *The Question Concerning Technology, and Other Essays*, translated by William Lovitt, 3–35. New York, NY: Harper & Row, Publishers, Inc., 1977.
[12] Tsai, Chin-Chung. "Beyond Cognitive and Metacognitive Tools: The Use of the Internet as an ‘Epistemological’ Tool for Instruction." *British Journal of Educational Technology* 35, no. 5 (2004): 525-536.
[13] Lehtonen, Anna, Arto Salonen, Hannele Cantell, and Laura Riuttanen. "A Pedagogy of Interconnectedness for Encountering Climate Change as a Wicked Sustainability Problem." *Journal of Cleaner Production* 199 (2018): 860-867.
[14] Jacobson, Mark Z., Mark A. Delucchi, Zack AF Bauer, Savannah C. Goodman, William E. Chapman, Mary A. Cameron, Cedric Bozonnat et al. "100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for 139 Countries of the World." *Joule* 1, no. 1 (2017): 108-121.
[15] Ballantyne, Anne Gammelgaard. "Climate Change Communication: What Can We Learn from Communication Theory?" *Wiley Interdisciplinary Reviews: Climate Change* 7, no. 3 (2016): 329-344.
[16] Jiang, Shiyan, Ji Shen, and Blaine E. Smith. "Designing Discipline-Specific Roles for Interdisciplinary Learning: Two Comparative Cases in an Afterschool STEM + L Programme." *International Journal of Science Education* 41, no. 6 (2019): 803-826.
[17] Seddon, Nathalie, Alexandre Chausson, Pam Berry, Cécile AJ Girardin, Alison Smith, and Beth Turner. "Understanding the Value and Limits of Nature-Based Solutions to Climate Change and Other Global Challenges." *Philosophical Transactions of the Royal Society B* 375, no. 1794 (2020): 20190120.

and applications.[18] Although the complexity of natural systems makes it difficult to fully map impacts, the quality of tools is improving at a steady pace. This approach is particularly important for Monitoring & Evaluating (M&E).

3. Digital tools in the Penang climate adaptation programme

Digital tools were essential for the design of the data-driven program, to map impacts already taking place. There is substantial global research on climate impacts from the IPCC. However, to bring local government and stakeholders on board with the development of the program, it is essential to present specific data for the region. The way data is presented must be targeted at the audience, so they can understand it as much as possible. For example, the data from the USM (Universiti Sains Malaysia)[19] climatology department shows the magnitude of changes in annual and monthly mean temperatures at Bayan Lepas climate station (located in Penang Island) during the 1951-2018 period. A significant increasing trend was found in both the annual and monthly mean temperatures from 1951 to 2018 at a 95% confidence level, with magnitudes ranging from 0.18 to 0.27°C/decade. The increase in mean temperature (°C) from 1951 to 2018 is 1.50°C. Although this is extremely high, the information is not fully understood by local government officials or by the local community, being perceived as *just numbers*. Showing remote sensing data on surface temperatures (USGS Landsat 8 TIRS data), however, has a greater impact, possibly because it's presented in a visual medium (see images 2, 2a).

Data analysis and research findings, particularly on the overall rise of surface temperatures[20], heavily supports the need to develop climate adaptation projects and programs in Malaysia. The presentation of this data to government officials was decisive to bring them on board with the program's development. The importance of digital tools will continue to be critical for M&E, showcasing the value of the strategies by assessing their impacts.

3.1 Science-driven approach: tools used in the design of the programme

Remote sensing is a trusted technology for analyzing climate systems. Coupled with machine-learning, this system promotes effective visual cognition which increases intuitive levels of spatial perception and understanding. The measurement of surface and atmospheric temperatures is achieved by capitalizing thermal-specific sensors such as Landsat's Thermal Infrared Sensor (TIRS) and aircraft-mounted Thermal Infrared Multispectral Scanner (TIMS). Temperature data is extracted by converting spectral radiance information into a Land Surface Temperature (LST) map using standard thermal constants. These maps record heat and energy emittance of objects signaling the patterns of thermal pollution. As the main cause of the UHI effect is the composition of land surfaces, linking LST and land cover data can substantially assist nature-based cooling strategies as they can quantify and predict direct and indirect cooling benefits of green spaces[21].

The assessment of surface temperatures in two moments in time cannot be used to estimate changes in climate, for that purpose climatology studies were developed using the data from the

[18] Galle, Nadina J., Sophie A. Nitoslawski, and Francesco Pilla. "The Internet of Nature: How Taking Nature Online Can Shape Urban Ecosystems." *The Anthropocene Review* 6, no. 3 (2019): 279-287.
[19] 2019. *Universiti Sains Malaysia*. http://www.usm.my/.
[20] Tang, Kuok Ho Daniel. "Climate Change in Malaysia: Trends, Contributors, Impacts, Mitigation and Adaptations." *Science of the Total Environment* 650 (2019): 1858-1871.
[21] Zhang, Yujia, Alan T. Murray, and B. L. Turner II. "Optimizing Green Space Locations to Reduce Daytime and Nighttime Urban Heat Island Effects in Phoenix, Arizona." *Landscape and Urban Planning* 165 (2017): 162-171.

weather station on the island. Remote sensing data on land surface temperatures can, however, assist in identifying different levels of impact of the UHI effect. The identification of neighborhoods which exacerbate the UHI effect allows for targeted intervention in an NbS program. Introducing green spaces and promoting airflow in the most heat-stressed areas is one of the main strategies of the PNBCAP. For Penang Island, land surface temperatures retrieved using Landsat 8 show an unequivocal UHI effect, with the maximum temperatures found in the UNESCO core site. This is also the area more lacking in green spaces. Retrieving surface temperature information related to past decades, it is possible to observe the increase of temperatures, which are a result of new construction (and subsequent UHI effect) combined with global warming. Landsat 8 TIRS data collected specifically for the PNBCAP in late February 1988 and in early March 2019 shows an increase of 7.4°C for maximum surface temperature and 2.4°C for minimum surface temperature (see images 2, 2a below). The impact of street trees on the reduction of surface temperatures and the UHI effect is clear, particularly in the Northwest part of the city, which is the area that has more tree-lined streets, being the coolest part of the city.

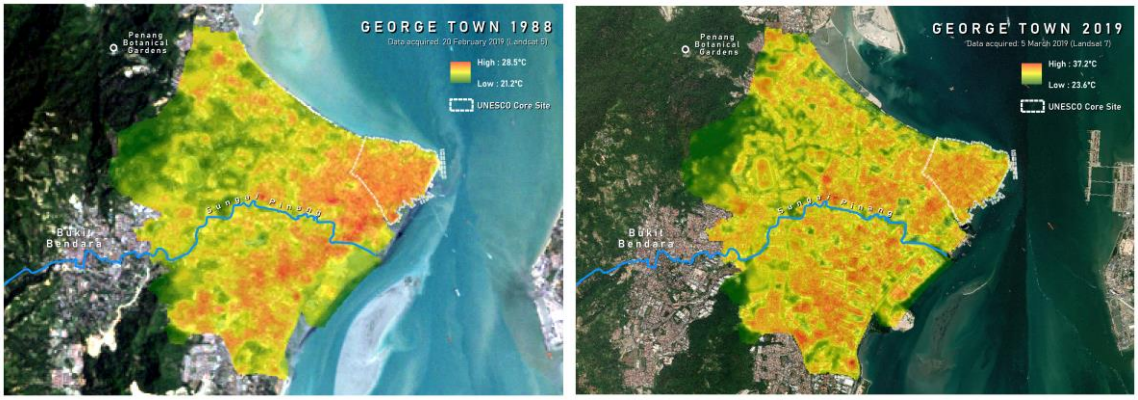

Image 2, 2a. Satellite image showing land surface temperatures in Penang, late February 1988 and early March 2019. Source: Produced by Think City using USGS Landsat 8 TIRS data, retrieved on 25 February 2019.

Remote sensing will be used in the program at two different levels: a) identifying the most heat stressed urban areas as priorities for intervention; b) monitoring the development of the program's impact in order to identify the most effective strategies for replication. Monitoring the impacts of the program in time is of great importance to inform and support the design and decision-making process. It will also allow for evaluation of different strategies, promoting evidence-based policy making.

Besides remote sensing, thermal imaging is also used at ground level with a thermal camera, providing on-site information regarding surface temperatures. It confirms remote sensing data for the above mentioned Northwest area, and for the most heat-stressed part of George Town (the UNESCO core site, which has almost no street trees). Thermal imaging of both areas taken on the same day (12.07.2019), just one hour apart, reveal a significant increase in surface temperatures in the UNESCO core site compared to the Northwest part of the city, with the maximum temperature increasing by 28.8 °C.

Images 3-3a. Thermal imaging of Jalan Brown, partially shaded tree-lined street in the Northwest part of George Town, Penang. **Images 4-4a**. Thermal imaging of Lebuh Gereja, non-shaded street in the hottest part of the city, the non-shaded UNESCO core site of George Town, Penang. Source: Produced by Think City using Perfect Prime IR0006 Thermal Imager Camera on 12 July 2019.

Thermal imaging of the partially shaded tree-lined street showcases lower temperatures than in the UNESCO core site. Even in this location, interruptions in canopy shading result in sharp surface temperature increases, as seen in images 3-3a.

3.2. Digital tools created for the PNBCAP

The digital tools that are being developed for the PNBCAP are mostly focused on knowledge transfer and DRR, through digital platforms and one APP.

3.2.1 Knowledge transfer platform

The creation of a knowledge transfer platform is a sub-component of the institutional capacity component of the PNBCAP, with an allocated budget of US$550,000. The platform will allow the capturing and dissemination of the methods and results from the PNBCAP, not only to other districts in Penang state, but also to other cities in Malaysia and in the Southeast Asian region.

The platform will ensure full transparency in the implementation process, with all stakeholders being informed of strategies, M&E tools and results. A dedicated website will be created, and monthly reports will be sent to all stakeholders. Besides enhancing the overall performance and speed of implementation of the PNBCAP, capacity building and knowledge transfer will be additional benefits for the institutions and departments involved. Beyond Penang, inter-municipal exchange platforms can serve as a multiplying factor in mainstreaming NbS into urban planning. The benefits of implementing the first NbS urban climate adaptation programme in Malaysia can therefore be extended to national and regional levels. Streamlining information regarding municipal adaptation will help other cities in Malaysia and in the Southeast Asia region to develop their own climate adaptation programs with a focus not only on resiliency but also on sustainability.

The creation of the platform will allow for the replication of the program's methodology, as well as the sharing of M&E results regarding the effectiveness of its strategies. This will include (but is not limited to): impacts on urban flooding and temperature reduction, improved social resilience,

and effectiveness of the different DRR strategies. The communications plan activities will be managed and mainstreamed via this platform. The platform will also have an advocacy role at local and national levels.

The knowledge component will be a vehicle for the communications outreach strategy with associated social media platforms. The goals for the communications strategy follow the four pillars of the PNBCAP social resilience components, which are: a) awareness, b) knowledge, c) capacity building and d) empowerment. The social media platforms will, therefore, focus on promoting awareness in climate change, sharing specific knowledge on the subject, assisting in building capacity and empower for action, in particularly among the most vulnerable communities. To maximize its impact, program partners will commit to share all posts in their own social media platforms.

It was agreed with the Ministry of Environment and Water to convert the knowledge transfer platform into a national urban adaptation platform for Malaysia. This will allow for all urban adaptation projects developed in the country to be showcased together in the same platform. In order for projects to be accepted for showcasing, a methodology for M&E of impacts must be followed and annual data uploaded to the platform. This will ensure that assessment of strategies takes place and is shared publicly, in a culture that typically avoids this approach to challenges.

3.2.2 The climate APP

An APP dedicated to DRR support will be developed under the Penang Climate Board, a sub-component of the institutional capacity component. The APP will be focused on:

1) Extreme rainfall events
    - Sending geolocated alarms in the case of extreme rainfall events, targeting residents of flood-prone areas.
    - Advising on unobstructed roads for evacuation of flooded areas.
    - Providing location and directions for shelters.
2) Heatwaves
    - Sending heatwave alarms, particularly targeting inhabitants of low-income housing and high UHI effect areas.
    - Advising on exposure and care of children up to 2 years old and elderly people, two demographic groups that are particularly vulnerable to heat stroke.
    - Advising on symptoms of heat stress and stroke and liaising with health support.
3) Women & girls support
    - A peer-support network focused on caretaking.
    - Advising and liaising with special services for facilitating and improving comfort in mobility.
    - Instructions for disaster events, sharing locations of women-only shelters and assisting with the challenging mobility of families under disaster circumstances.

3.2.3 An open collaborative online database for climate resilient urban tree species

A study was developed with the monetary prize of the Climathon Global Cities Award 2020, focusing on the climate resilience of urban tree species in Malaysia, assessing 220 species according to eight predetermined climate criteria. Urban trees have a life expectancy of up to 80 years old and, as the climate is changing, it is important to understand which species can adapt to the circumstances of the future climate. The goal of the research was to identify the most

resilient species to the expected climate impacts, and therefore more likely to survive the climate circumstances of the future. The results show that urban tree species are already being impacted by climate change in the region. It also became clear that, as climate change progresses, we will need to keep recording the impacts on different tree species. This realization led to the creation of an *open-collaborative online database* that documents climate impacts on tree species in the country, and their main traits, including those that contribute the most to climate adaptation.

The database will contain the assessments for the 220 species according to the eight climate criteria used in the research. Additional criteria are included, such as the urban suitability and the biodiversity, cultural, and economic value of tree species in Malaysia. The platform should also contribute to diversify the number of tree species planted in urban areas; although Peninsular Malaysia has around 2,830 tree species[22], only a small selection is planted in urban spaces. The database is a natural extension of the research, given the diversity of species in the region that are yet to be understood in terms of resilience and performance in urban contexts.

The platform aims to function as a powerful tool for informing future-oriented urban forest management and sourcing tree species. It also seeks to catalyze action for policy change and the ex-situ conservation of species. Other databases that document plant and/or tree traits have been developed for other parts of the world, such as one for the Australian flora[23] and another for Euro-Mediterranean trees[24].

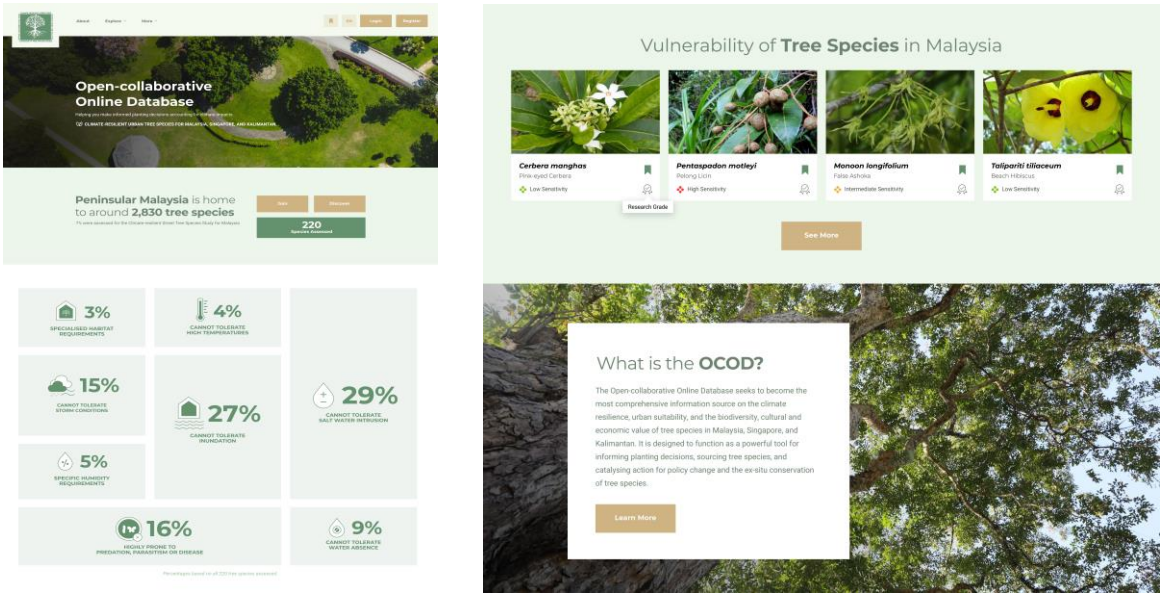

Image 5. Working template for the open-collaborative online database.

The assessments of tree species are aligned with the criteria developed for the climate-resilient urban tree species study. The platform will aggregate these to create more robust data and provide a comprehensive overview of the species' traits. This composite answer is automatically

[22] Ng, F. S. P., C. M. Low, and N. S. Mat Asri. "Endemic Trees of the Malay Peninsula. Research Pamphlet 106." *Forest Research Institute Malaysia, Kuala Lumpur. 118p* (1990).
[23] Falster, Daniel, Rachael Gallagher, Elizabeth H. Wenk, Ian J. Wright, Dony Indiarto, Samuel C. Andrew, Caitlan Baxter et al. "AusTraits, a Curated Plant Trait Database for the Australian Flora." *Scientific Data* 8, no. 1 (2021): 1-20.
[24] Monnet, Anne-Christine, Kévin Cilleros, Frédéric Médail, Marwan Cheikh Albassatneh, Juan Arroyo, Gianluigi Bacchetta, Francesca Bagnoli et al. "WOODIV, a Database of Occurrences, Functional Traits, and Phylogenetic Data for all Euro-Mediterranean trees." *Scientific Data* 8, no. 1 (2021): 1-11.

updated as new assessments are published. Users can also add new species, subspecies, or varieties to the platform. Sensitivity levels will be associated with a confidence score and moderators will review submissions to ensure that the criteria are applied consistently, and that supporting information provided agrees with the binary answer selected. By developing a curated dataset on 38 traits, the online database helps remedy the shortcomings in Malaysian and global biodiversity resources.

4. Conclusions

Choosing a NbS approach for a climate adaptation program is a data-driven decision, given the abundance of evidence, not only on its cost-effectiveness, but also overall effectiveness when compared with alternative strategies. Considering the multitude of crises humanity is facing, selecting this option is also a way of limiting impact on the biodiversity, air pollution and food production crises. Seeking to reduce human activity negative outputs to the environment (GHGs and other types of waste) must become a global priority. This is particularly obvious in terms of mitigation, whereby using green spaces, particularly trees, we are reducing the use of air conditioning and therefore of its associated emissions; on the contrary, they sequester carbon, even though the amount of carbon sequestration by urban green spaces is limited.

Human habitat on planet Earth is threatened in the short term by industrial civilization, to which the secretary general of the UN referred recently as a *War on Nature*. This is seemingly paradoxical, as humans are part of nature. Environmental philosophers have been addressing this by pointing out that the separation between the two is deeply engrained in philosophy since its early stages and a revision may be needed. Given the challenges we are faced with now, nature must be regarded as the preferential infrastructure to be invested in, developed, and expanded on the planet. As humanity is fully dependent on nature's provision of life supporting systems, we must enhance as much as possible these benefits by expanding natural or artificially vegetated areas. This approach does not undervalue the potential of technology, on the contrary. Digital tools can become the key factor to develop a more balanced approach to the environment, and in supporting the safeguard of the most vulnerable communities, promoting local, national, and international equity.

Humanity's relation with nature should be re-examined if we are to survive. Digital tools can substantially contribute, through knowledge dissemination, to this necessary shift of global mindsets towards reintegration of humans and nature, away from the resource-extracting mentality that has brought us to this age of crises.