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Speculative Design for Sustainable Urban Mobility: E-Bike Futures and Data-Driven Innovation

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This research explores the integration of speculative design within Taipei's public bicycle service to propel the achievement of net-zero emission strategies and Sustainable Development Goals (SDGs). It introduces a sustainable energy model tailored to enhance the public bicycle system amid rising global environmental challenges. Using the User Experience Questionnaire (UEQ) and the System Usability Scale (SUS), the study evaluates Taipei's YouBike 2.0 service and its associated apps, revealing a positive reception but noting a preference for enjoyment over practical utility and room for improvement in app perception. Further, it presents a pilot survey leveraging data-driven micro-electricity generation technology in urban infrastructure, integrating cutting-edge technologies like AI and real-time data to foster sustainable urban mobility. The research culminates in speculative design scenarios that envision future e-bike systems seamlessly integrated into smart city networks, suggesting a transformative role for e-bikes in urban transport sustainability.

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1. Introduction

In the contemporary era, the specter of global warming and escalating temperatures looms large, precipitating multifaceted international challenges. Nations across the globe find themselves compelled to collaborate to address this pressing issue. The surge in global temperatures not only instigates a cascade of climatic alterations but also intensifies the incidence of erratic weather phenomena and extreme climatic events. This ecological upheaval reverberates through diverse ecosystems, profoundly impacting both fauna and flora, including the very fabric of human existence.

Cognizant of the imperative for decisive action, Taiwan has embarked on a resolute journey towards achieving net-zero emissions by the year 2050, as delineated in its visionary blueprint, "Taiwan’s Pathway to Net-Zero Emissions." This strategic framework underscores pivotal transition strategies encompassing energy, industrial, lifestyle, and social dimensions, underpinned by robust technological research and development initiatives and fortified by legislative measures aimed at climate mitigation. The blueprint delineates twelve key strategies meticulously designed to operationalize the overarching net-zero objective, with the dual aspiration of propelling economic prosperity, fostering green financing mechanisms, and fortifying societal well-being[4].

President Tsai Ing-wen's proclamation of Taiwan's unwavering commitment to the 2050 net-zero ambition in April 2021 marked a seminal milestone in the nation's climate trajectory. The subsequent passage of the Climate Change Response Act in January 2023 further entrenched Taiwan's resolve towards attaining net-zero emissions through statutory imperatives. Nonetheless, given its pronounced dependence on imported energy reservoirs, Taiwan confronts a formidable conundrum in striking a delicate equilibrium between fiscal viability and environmental sustainability. Against this backdrop, the government's strategic focus on decarbonization initiatives and substantial investments in renewable energy infrastructure emerge as pivotal pillars underpinning Taiwan's quest to realize its net-zero aspirations.

This study proffers an incisive exploration of the transformative potential of e-bikes in reshaping urban mobility paradigms, presenting an innovative roadmap for cities to chart a course toward a sustainable, efficient, and net-zero emission future. Leveraging a synergistic fusion of speculative design methodologies and data-driven innovation imperatives, this research seeks to illuminate the transformative role of e-bikes as linchpins in orchestrating a holistic metamorphosis of urban transportation ecosystems. By delineating a strategic blueprint underscored by visionary foresight, this study will furnish urban policymakers and stakeholders with actionable insights and strategic imperatives essential for navigating the labyrinthine terrain of sustainable urban mobility in an era fraught with climatic exigencies and environmental imperatives.

The Taipei City government, in partnership with New Taipei City, has actively pursued sustainable development initiatives in alignment with the United Nations Sustainable Development Goals (SDGs). Both cities have implemented a range of measures aimed at reducing carbon emissions, promoting green transportation, and fosteringvarious measures to reduce carbon emissions, promote green transportation, and foster sustainable practices. Taipei City has placed particular emphasis onemphasized inclusiveness, diversity, environmental protection, and gender equality to establish a foundation for quality living and sustainable development. Additionally, the New Taipei City government has undertaken initiatives to integrate sustainable practices into public construction, enhance building energy efficiency, and promote green living through projects such as green commuter bike paths. These collective efforts are closely alignedlign closely with the SDGs, reflecting a commitment to sustainable urban development and environmental stewardship.

Furthermore, collaboration with organizations like YouBike has promoted shared mobility and green transportation, furthering the overarching objective of achieving sustainable urban development.

Smart mobility has emerged as a pivotal strategy in advancing more sustainable and resilient communities, aligning with key SDGs:

1. SDG 3: Good Health and Well-being: By advocating for non-motorized transportation modes like bicycles and walking, smart mobility can contribute to healthier lifestyles, reduced air pollution, and enhanced public health.

2. SDG 7: Affordable and Clean Energy: Smart mobility solutions promote the adoption of energy-efficient and low-emission transportation options, such as electric vehicles, thereby contributing to a decrease in greenhouse gas emissions and an improvement indecreasing greenhouse gas emissions and improving air quality.

3. SDG 11: Sustainable Cities and Communities: Smart mobility initiatives support the creation of safe, inclusive, and sustainable urban environments. By optimizing transportation systems and promoting sustainable alternatives, smart mobility can mitigate congestion, enhance air quality, and improve the overall livability of citiescities' overall livability.

4. SDG 13: Climate Action: Through the promotion of energy-efficient and low-emission transportation modes, smart mobility can play a crucial role in mitigating the adverse impacts of climate change and reducing greenhouse gas emissionSmart mobility can play a crucial role in mitigating the adverse impacts of climate change and reducing greenhouse gas emissions by promoting energy-efficient and low-emission transportation modes.

2. Literature Review

2.1 Taipei's YouBike System

The Taipei bike-sharing system, known as YouBike, exemplifies a successful integration of convenience, sustainability, and technology in urban mobility. Launched as a collaboration between the Taipei City Department of Transportation and Giant Bicycles, YouBike has expanded its reach and technological capabilities, significantly influencing Taipei's urban landscape and lifestyle. The system is an essential part of the city's urban transportation network, emphasizing the importance of understanding dynamics, patterns, and interactions within such systems to optimize performance and enhance user experience.

Eric Khun discusses the accessibility and convenience of Taiwan's YouBike bike-sharing program. It emphasizes personal experiences with YouBike, highlighting its superiority over other modes of transport in Taipei due to affordability, maintenance, and accessibility. The integration with the universal EasyCard payment system and the presence of extensive biking paths have been pivotal in YouBike's success. This user-centric approach, combined with data-driven optimization of station locations and bike availability, demonstrates the system's adaptability and focus on user satisfaction[10].

2.2 YouBike 1.0 and 2.0

The evolution from YouBike 1.0 to 2.0 signifies a major advancement in public bike-sharing infrastructure, reflecting an increased focus on user experience, convenience, and environmental sustainability. The transition from the recognizable orange color of YouBike 1.0 to the sophisticated pearl white and yellow scheme of YouBike 2.0 exemplifies the system's aesthetic refinement[15]. The incorporation of solar-powered technologies, enhanced rental options, and temporary parking features further demonstrate Taiwan's commitment to enhancing the accessibility and convenience of the YouBike system ([14]; [2]).

The iterative development of the YouBike system exemplifies Taiwan's commitment to fostering sustainable urban mobility solutions. By offering a convenient, affordable, and eco-friendly mode of transportation, YouBike empowers residents and visitors to navigate Taiwanese cities with reduced environmental impact. The successful transition from YouBike 1.0 to 2.0 underscores the importance of user feedback and technological advancements in optimizing public bicycle-sharing programs.

2.3 YouBike 2.0E

The introduction of the YouBike 2.0E in Kaohsiung City, Taiwan, in 2021 shows an innovative upgrade, integrating electric-assist technology into the already successful YouBike 2.0 system, represents a new era in urban mobility by making cycling more accessible and less physically demanding for a broader spectrum of users[12].

YouBike 2.0E, equipped with a high-capacity lithium battery, offers electric assistance to riders, thereby reducing the effort required to climb hills and travel longer distances. This feature is particularly appealing in a cityscape with varying topographies, making it an attractive option for both daily commuters and tourists. The bike's smart panel, which displays the battery level and issues low battery reminders, enhances user convenience, ensuring a seamless and enjoyable cycling experience.

The integration of YouBike 2.0E with the existing YouBike 2.0 system facilitates a unified user experience. Riders can use their current YouBike memberships or a simple QR code scan via smartphone to access the bikes, maintaining the system's hallmark of user-friendly access and convenience. This integration allows for the use of the same docking stations and app, ensuring that the transition between traditional and electric-assist bikes is as smooth as possible.

Kaohsiung City's YouBike 2.0E system is a prime example of innovation in urban mobility. By offering electric-assisted bicycles, YouBike 2.0E makes cycling not only more enjoyable but also accessible to a wider range of residents, including those who might have found traditional cycling too strenuous. The city government further promotes its adoption with subsidies for the first 30 minutes of use and discounted rates for residents. These incentives aim to reduce traffic congestion and air pollution by encouraging a shift towards eco-friendly transportation. YouBike 2.0E, along with the government's commitment to its success, exemplifies Kaohsiung's pursuit of sustainable urban development and environmental responsibility[9].

2.4 Speculative Design for Bike-Sharing Innovation

Speculative design, an innovative design methodology that explores potential futures through the creation of visionary scenarios, offers a critical lens for the evaluation of bike-sharing systems. It stands as a pivotal bridge connecting the immediate challenges faced in urban mobility with the vast opportunities of tomorrow, facilitating a proactive engagement among stakeholders to envision and meticulously prepare for an array of future possibilities.

A recent study by Ye and Bai[16], published in Hindawi, navigates the intricate relationship between bike-sharing and public transit, marking it as a blend of cooperation and competition (coopetition). The advent of bike-sharing, propelled by advancements in mobile technology, has significantly altered the landscape of urban mobility by providing an efficient solution for "first/last mile" challenges in connecting to public transit systems. Despite the clear advantages of bike-sharing, such as enhanced travel efficiency, diminished congestion, and environmental benefits, there are rising concerns about its potential to divert users from public transit.

This comprehensive review illuminates the complex dynamics between these transportation modes across three pivotal research domains. Initially, it investigates the overarching interaction between bike-sharing and public transit, scrutinizing their collective impact on urban mobility patterns. It then probes into user behavior, employing surveys of bike-sharing users to ascertain whether bike-sharing substitutes for public transit journeys. The exploration concludes by analyzing transaction data, determining how bike-sharing either complements or competes with public transit in varied urban settings[16].

The review's principal conclusion underscores the nuanced impact of bike-sharing. It unveils a sophisticated pattern of substitution and complementary effects swayed by several factors, including trip distance, purpose, and urban environment characteristics. This finding is pivotal, highlighting the necessity for policies that foster a harmonious coexistence between bike-sharing and public transit, aiming for a cohesive and sustainable urban transport framework[16].

Another study by Massachusetts Institute of Technology, Department of Urban Studies and Planning, 2019. investigates the impact of dockless bike-sharing on Beijing's rental market, focusing on how it affects the rent price gradient for subway accessibility. Introducing dockless bikes in Beijing slightly flattened the rental price gradient for apartments within a 3km radius of a subway station. The effect varied across different areas, with the price gradient becoming steeper in more developed areas and flattening in less developed ones. The study also found that switching from walking to biking for subway commutes could save about 8.3 minutes per trip on average[18].

This insight leads us to ponder the transformative effects that future innovations in bike-sharing could have on urban dynamics and accessibility, alongside their potential to reshape housing markets and guide urban planning practices.

2.5 Bike Sharing in Sustainable Cities

According to an in-depth exploration of bicycle-sharing schemes and their impact on sustainable urban mobility, Peter Midgley's[11] exhaustive analysis uncovers the significant potential of bike-sharing to navigate and solve the complexities of urban sustainability.

The study highlights the explosive growth of bike-sharing, evidencing a crucial shift towards its integration into the urban public transit fabric. It intricately examines the technological progress that propels the evolution of bike-sharing from its nascent first-generation models to the advanced capabilities of fourth-generation systems, which meld GPS tracking, solar-powered docking stations, and electric bikes to optimize both user experience and service efficiency. The research meticulously outlines bike-sharing's broad spectrum of benefits, encompassing enhanced

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urban mobility, significant cuts in traffic congestion and pollution, and the cultivation of cycling as an accessible, environmentally sustainable, and health-promoting mode of transport[11].

Another research shows insights from data analysis across 38 worldwide bike-sharing programs, showcasing the impact on urban mobility. Technological advancements drive the proliferation of these systems globally, yet variations in usage patterns emerge across different urban settings, influenced by city layouts and cultural factors. This study points out key challenges, such as bike redistribution and safety concerns, while spotlighting technological solutions like real-time tracking. By meticulously analyzing bike-sharing data, cities can refine these systems, bolstering sustainable transport initiatives. Emphasizing the significance of bike-sharing data, this research underlines its role as a pivotal resource in enhancing sustainable urban mobility, with ongoing data analysis and interpretation enabling stakeholders to fine-tune bike-sharing systems for improved integration with existing transport networks and fostering greener commuting habits[13].

In addition to Zhang[17] focusing on China, this study investigates the sustainability of bike-sharing systems within urban environments, analyzing how they contribute to reducing dependence on private vehicles. This study pinpoints essential characteristics and similarities among China's successful bike-sharing initiatives, assessing their efficacy in meeting environmental and social sustainability objectives. A pivotal factor in these programs' success is their thoughtful design and seamless integration into the urban landscape, which ensures they are accessible and convenient for short city trips. The research highlights bike-sharing's contribution to fostering cleaner, more energy-efficient modes of transportation, aiding in better traffic management, reducing emissions, and encouraging physical activity through active travel. Despite the expansion of bike-sharing programs, the study emphasizes the need for additional research to thoroughly gauge their influence on urban transport systems, especially regarding their planning, design, and operational models.

3. Research Method

The research framework unfolds through a three-phased approach. In Phase A, 'Background Research', the groundwork is laid by an Introduction and Motivation, detailing the impetus behind the study, followed by outlining the Research Purpose and conducting a thorough Literature Review. In Phase B, 'Speculative Design', the framework engages in Defining the Context for the Debate, brainstorming and Identifying Problems, and Crafting a Visionary Future Scenario. Additionally, it entails Materializing the Scenario to Engage and Challenge the Audience. Phase C, the 'Conclusion', initiates a Discussion on the findings and plots a course for Future Work. The case study of the Taipei Bike Sharing System, with an emphasis on closing the transportation accessibility gap through innovative Electric Bike technology and design, serves as the practical application of the Speculative Design phase, aligning with the SDGs and NetZero commitment. The culmination of this research is the conception and evaluation of YouBike 2.0, analyzing both Service and Application Experiences via the UEQ and SUS methodologies.

3.1 Qualitative Research with Thick Data Analysis

Before entering the design phase, this study centralizes thick data in qualitative research through observational methods to assess the existing public bicycle service YouBike 2.0 and user behavior in Taipei City. An effort to uncover individual experiences enriches multiple perspectives to pinpoint core issues and targets of the product, ultimately conducting a strengths and weaknesses assessment of the current system through design thinking.

In contrast to big data's capability to reveal broad patterns, thick data delves into the qualitative aspects of data. Qualitative methods like participant observation capture the nuanced and unique human experiences and innovative ideas [6] that reveal the human emotions and sociocultural dimensions behind data that are not measurable in numbers [1]. Hence, this study opts for thick data as a research tool in the current data-driven research milieu due to its unique advantages.

In our investigation, we employed an observational method to explore the YouBike 2.0 system, undertaking a journey from the National Taipei University of Technology (NTUT) to the National Taiwan University (NTU). Our experiential observations synthesized the system's strengths and challenges, with perceived benefits including enhanced physical health, promotion of local businesses, simplified transactions via Easy Card, efficient city navigation, and economical transport options. Conversely, we also recognized challenges confronting YouBike, such as inconsistencies in bike availability information, bicycle shortages during peak times, complicated registration processes, a lack of bike return follow-ups, and insufficient parking facilities.

3.2 Quantitative Research

This study employed the User Experience Questionnaire (UEQ) and System Usability Scale (SUS), primarily targeting users who have ridden YouBike 2.0 in Taipei City. The objective was to understand user behaviors, overall service experience, and usability assessment of the app, identifying potential improvements for the anticipated future service.

An analysis conducted on 62 sample users who have experienced riding YouBike 2.0 revealed that in the domain of Pragmatic usability, aspects of 'Attraction' and 'Clarity' correlate highly at 0.69, signifying that the majority of respondents regard YouBike 2.0 as a supportive transportation tool. Furthermore, within the Hedonic usability domain, aspects of 'Novelty' and 'Development' (Table 1) have a strong correlation of 0.64, suggesting that the users concur with YouBike being a smart transportation and environmentally sustainable option.

Table 1: UEQ of YouBike 2.0 (left) ; Pragmatic Quality of YouBike 2.0 (center) ; Hedonic Quality of YouBike 2.0 (right)

1.Attraction	Obstructive	OOOOOOO	Supportive
2.Clarity	Complicated	OOOOOOO	Simple
3.Efficiency	Inefficient	OOOOOOO	Efficient
4.Comprehension	Understandable	OOOOOOO	Not understandable
5.Stimulation	Acceptable	OOOOOOO	Rejected
6.Reliability	Useful Service	OOOOOOO	Useless Service
7.Novelty	Smart Mobility	OOOOOOO	Non-Smart Mobility
8.Developmental	Eco-friendly and sustainable	OOOOOOO	Non-environmentally sustainable

Pragmatic Quality	
Items	Correlation
1.2	0.69
1.3	0.55
1.4	0.40
2.3	0.29
2.4	0.53
3.4	0.30
Average	0.46
Alpha	**0.77**

Hedonic Quality	
Items	Correlation
5.6	0.36
5.7	0.43
5.8	0.43
6.7	0.54
6.8	0.47
7.8	0.64
Average	0.48
Alpha	**0.79**

Overall, the results are positive for both Pragmatic and Hedonic qualities, scoring above average, indicating that YouBike 2.0 satisfies the needs of its users. It is, however, noteworthy that the hedonic value perceived from YouBike 2.0 services is considered to exceed its pragmatic quality (figure 1).

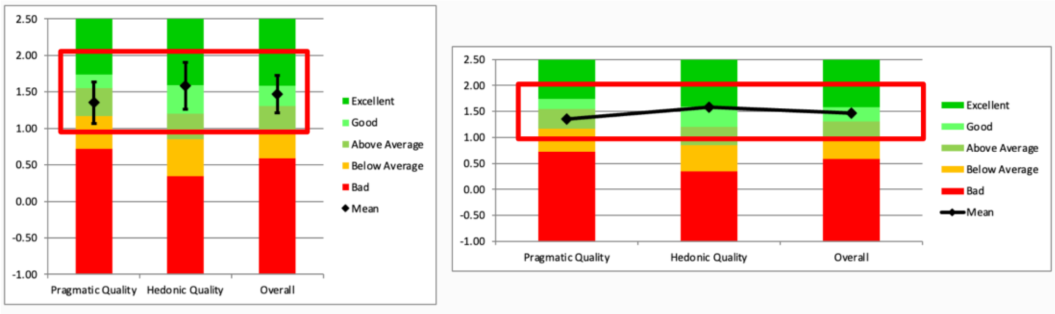

Figure 1: Benchmark graph for YouBike 2.0

10 Questions of the SUS	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average of scores
I think that I would like to use this APP frequently.	○	○	○	○	○	3.15
I found the APP unnecessarily complex.	○	○	○	○	○	2.79
I thought the APP was easy to use.	○	○	○	○	○	3.55
I think that I would need the support of a technical person to be able to use this APP.	○	○	○	○	○	1.96
I found the various functions in this APP were well integrated.	○	○	○	○	○	3.09
I thought there was too much inconsistency in this APP.	○	○	○	○	○	2.75
I would imagine that most people would learn to use this APP very quickly.	○	○	○	○	○	3.62
I found the APP very cumbersome to use.	○	○	○	○	○	2.68
I felt very confident using the APP.	○	○	○	○	○	3.36
I needed to learn a lot of things before I could get going with this system.	○	○	○	○	○	2.25

SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

Figure 2: SUS individual average scores of YouBike 2.0 (left) ;
SUS score of YouBike 2.0 (right)

Further analysis of 53 sample users who have ridden YouBike 2.0 and used the APP illustrates that the service is mainly utilized for commuting and short leisure trips, with most usage times not exceeding 30 minutes, particularly among users aged 19-29 who tend to use the service 1-3 days per week. The SUS analysis indicates that most participants could swiftly comprehend the app's functionality without the need for external assistance and deem the app to be practical. Nevertheless, there is a unanimous belief that improvement is needed, such as the app not being particularly intuitive and lacking in comprehensive integration. Despite having ridden YouBike 2.0, some users have not engaged with its app, and the disparity between higher evaluations from first-time users and those with accumulated experience should be noted. Overall, the app's usability score is 60.85, classified as 'poor' (figure 2), reflecting a negative perception of the current app. Importantly, despite the app's failure to meet the desired user-friendly experience, the receptiveness to riding remains positive. This indicates that the present service quality does not affect the users' willingness to try and continue using YouBike 2.0.

3.3 Speculative Design

Our study adopts a speculative design framework to envision and prototype sustainable urban transport solutions centered around electric bicycles (e-bikes), aiming to achieve net-zero emissions. Guided by methodologies proposed in "The Young Designer's Guide to Speculative and Critical Design"[8], our approach unfolds in three steps.

Step 1:defining the context for debate

Initially, we engaged in extensive observation, dialogue, and reflective thinking to outline the context for our speculative design endeavor. The focal question driving our inquiry was, "How can ‘big data-driven technology' and 'Net Zero Emissions' affect the public bike system?" This phase involved analyzing existing literature on urban mobility, transportation sustainability, and big data's role in enhancing public infrastructure services.

Step 2:ideate and find problems, and create a scenario

In step 2, our team identified and prioritized five key challenges impacting users of e-bike sharing systems: health, carbon emissions, electricity usage, user willingness, and perceived value. Utilizing quantitative (big data) and qualitative (thick data) methodologies allowed for a rich, multidimensional understanding of these issues. For instance, big data analysis revealed integration challenges within the current bike-sharing app (User Experience Questionnaire - UEQ and System Usability Scale - SUS insights), whereas thick data—gathered through direct observations and user interviews—highlighted the importance of physical health benefits and the need for a more seamless app experience.

Step 3: Create a scenario, and materialize the scenario to provoke an audience

In step three, we focus on “How we incorporate data into our designs” and “Materialize the scenario to provoke an audience.” Enhancing the E-Bike Sharing App: Addressing the fragmented user experience identified through UEQ and SUS analyses, we redesigned the app to provide a unified platform for accessing services, tracking rides, and viewing health and environmental impact data.

Simplifying User Interaction: To tackle the issues of app intuitiveness and registration complexity, we introduced an introductory tutorial within the app, streamlining the onboarding process and enhancing navigational ease.Promoting Sustainable and Engaged Usage: Drawing from the insight that cost-effectiveness and environmental sustainability are key motivators for users, we proposed a gamified challenge system with rewards to incentivize sustained use of e-bikes and deepen user engagement with the service’s environmental benefits.

This integrative, data-informed approach provides actionable insights for enhancing the e-bike sharing experience and contributes to the broader discourse on sustainable urban mobility. By weaving together big data analytics and thick data observations, our speculative design process offers a nuanced pathway toward realizing eco-friendly and user-centric transportation solutions. Future work will focus on prototyping these solutions within real-world settings to evaluate their impact on promoting sustainable urban transport behaviors.

3.4 Objective, Goal, Strategy and Measure (OGSM)

Following our in-depth research and speculative design exploration, we applied the Objective, Goals, Strategies, and Measures (OGSM) framework to transition our findings into a strategic plan. This framework guided us in setting a clear objective: to improve the e-bike sharing experience with a focus on sustainability and user engagement.

We identified specific goals addressing the five key challenges previously outlined, including enhancing health benefits, reducing carbon emissions, optimizing electricity use, increasing user willingness, and improving perceived value. Strategies were developed for each

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goal, such as integrating comprehensive data analytics into the app for a unified user experience and introducing gamification to encourage engagement.

A crucial component of our strategy was implementing a digital dashboard. This tool allowed us to measure the effectiveness of our strategies in real time, adjusting as necessary to ensure our goals were met. Simultaneously, we outlined an action plan to develop a Minimum Viable Product (MVP), enabling us to test and refine our approach practically. The use of the OGSM framework thus provided a structured pathway from speculative design insights to the actionable implementation of sustainable urban mobility solutions, exemplifying a model for applying strategic planning in design research.

4. Design Concept and Implementation

4.1 Overview of the Service

In response to the aforementioned preliminary research, this study conceptualizes a service scheme for electric bicycles in Taipei City through speculative design. It encompasses both tangible and application aspects, such as micro-electricity utilization, AI assistance, location-based navigation, and real-time data, with the aim of enhancing the connection between the application and the riding experience. The objective is to better integrate the YouBike 2.0 E into the smart city transportation network, offering an environmentally friendly, efficient, and convenient mode of transportation.

4.2 Data-Driven Dimension

To address the urgent need for sustainable urban transportation solutions, this study proposes the utilization of the micro-electricity generated by YouBike 2.0 E to power its own system and city micro-electricity devices, including mobile phones, household bicycles, traffic signals, street lights, and other public facilities. (The detailed process of energy application for electric-assist bicycles is illustrated in Figure 5 below.) When users return the electric-assist bicycles, the batteries will be connected to the station. Upon successful energy storage at the station, users will receive a rebate as a reward for generating micro-electricity.

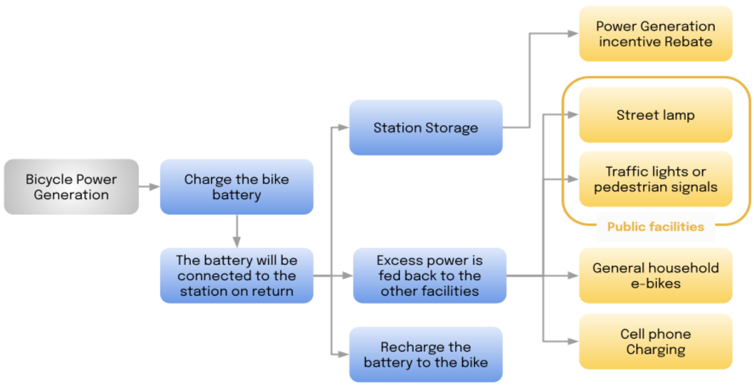

Figure 5: Energy Application Flowchart for Electric-Assist Bicycles

The micro-electricity mentioned above is generated by the user pedaling, a principle derived from Spinetics's Cydekick device (see Figure 6). This device operates on electromagnetic induction, consisting of a rotor on the wheel and a stator on the frame. As the wheel turns, the rotor drives the stator to generate electricity, stored in a battery installed internally. This allows the electric-assist bicycle to use the stored electricity to extend its range and enhance the user experience.

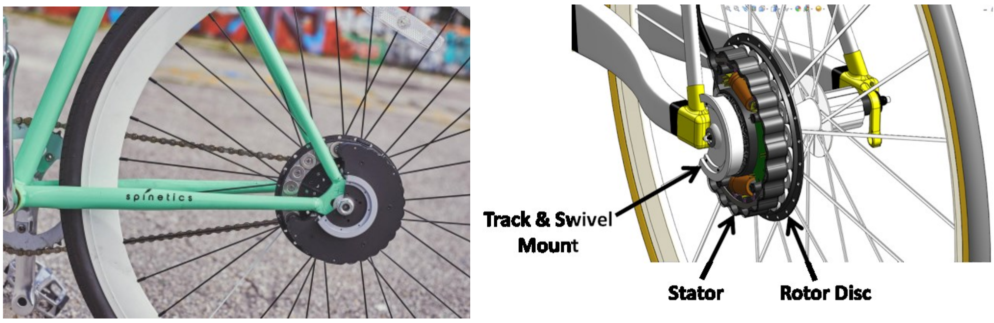

Figure 6: Principle of Micro-Electricity Generation
On the left,the Spinetics's Cydekick device, and on the right,
the principle of how the device is composed.

To explore the potential of Taipei's bicycle manufacturing for micro-electricity generation and carbon emission reduction, this study conducted a pilot survey on the pedal power of bicycles through data integration and micro-electricity calculation. It used data from the "Taipei City Public Bicycle 2.0 Rental Records" on Taipei's open data platform as a basis for the investigation. For instance, on July 1, 2023, the total cycling time for the day amounted to approximately 72,270 hours. According to Emmanuel Cosgrove, one hour of cycling can generate about 0.11 kWh of electricity[5]. Therefore, using Formula 1 below, it is estimated that bicycles can generate about 7,949.7 kWh of electricity per day.

Furthermore, based on the data, the total number of riders on July 1, 2023, was 104,347. Transitioning from car use to bicycle riding can reduce carbon footprints by approximately 3.2kg per day per person [3]. Assuming all these individuals switched from cars to bicycles, Formula 2 calculates a potential reduction of about 333,910.4 kg in daily carbon footprints. Additionally, generating 1 kWh of electricity produces 0.495 kg of CO_2[7]. Hence, based on the electricity generated in one day as mentioned, cycling instead of using fossil fuels for electricity can reduce carbon emissions by approximately 4 tons (Formula 3).

The analysis of the "Taipei City Public Bicycle 2.0 Rental Records" also revealed that single trips lasting 15-30 minutes accounted for more than half of the total cycling time, indicating significant contributions by this group to micro-electricity generation, carbon emissions, and footprint reduction. These findings highlight YouBike's potential in achieving net-zero emission strategies and Sustainable Development Goals (SDGs).

Formula 1 : 0.11 (kWh) * 72,270 (hr) = 7,949.7 (kWh)
Formula 2 : 3.2 (kg) * 104,347 = 333,910.4 (kg)
Formula 3 : 0.495 (kg) * (7,949.7 (kWh) / 1000) = 3.9351015 (kg)

4.3 Minimum Viable Product（MVP) Analysis

Synthesizing the above, this study, utilizing the System Usability Scale (SUS), identified generally poor perceptions among Taipei's public towards the YouBike 2.0 app. Through OGSM analysis, further actions for the Minimum Viable Product (MVP) were established. Figure 7 illustrates the proposed prototype design and usage flow for app optimization. When users first interact with the app, they encounter an introductory page explaining the utility of the generated electricity. Post-navigation, users can view health and carbon emission records and choose whether to provide feedback to manufacturers or government bodies to enhance the experience. To encourage usage and achieve net-zero emissions, the app will also incorporate gamification elements, where users completing challenges can earn coupons.

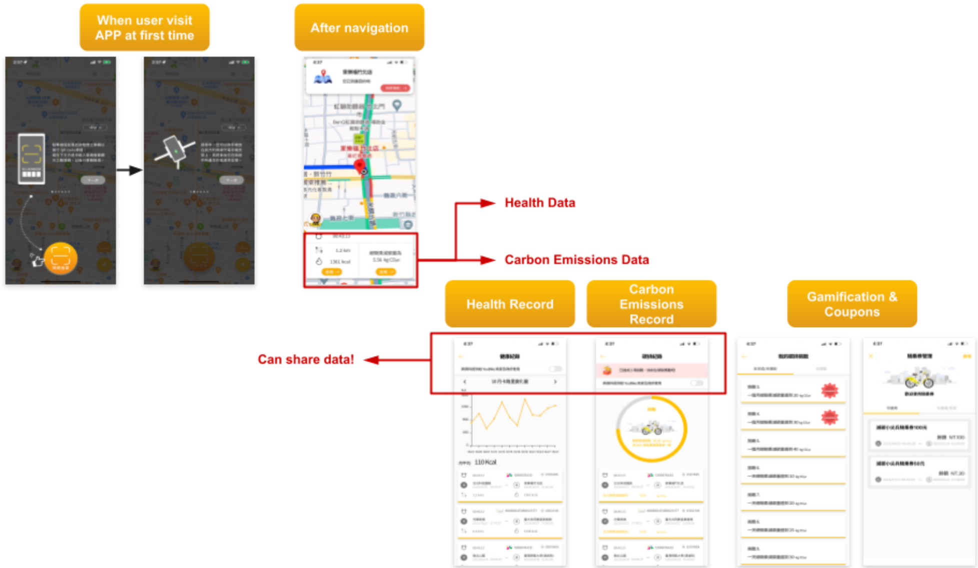

Figure 7: Application Optimization Prototype

4.4 The Ecosystem Analysis

Subsequently, this study conducted a feasibility and stakeholder analysis across three dimensions for the aforementioned concept (Figure 8), aiming to construct a comprehensive service ecosystem. This analysis encompasses three aspects, each pivotal to the YouBike ecosystem. Under "Sustainability," stakeholders aim to ensure the sustainability of urban transportation and the environment, positioning public bicycles as an indispensable part of this shared vision. In the "Feasibility" segment, the practicality and viability of integrating public bicycles with a broader electrical infrastructure are highlighted, emphasizing sustainable and green energy solutions. The "Viability" aspect brings financial considerations to the forefront, where stakeholders play a crucial role in ensuring the financial feasibility of public bicycles, including payment processing and revenue management. This diagram comprehensively displays the interconnected stakeholders and their roles in supporting public bicycles, emphasizing sustainability, practicality, and financial stability in the context of urban transportation and environmental well-being.

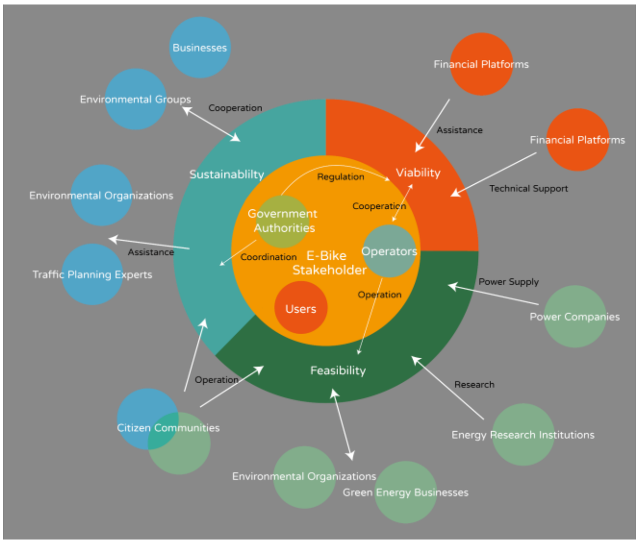

Figure 8: Ecosystem and Stakeholder Analysis Diagram

4.5 SDGs Supporting Analysis

In today's society, achieving the Sustainable Development Goals (SDGs) is crucial for promoting health, well-being, affordable and clean energy, sustainable cities and communities, and climate action. The service scheme proposed in this study aligns with various aspects of the SDGs:

1. SDG 3: Good Health and Well-Being: The public bicycle system can encourage individuals and communities to adopt more environmentally friendly actions, such as providing carbon reduction records and coupons, thereby promoting health. Establishing a shared bicycle system with a focus on health encourages people to use bicycles for physical exercise, reducing air pollution and enhancing users' health.
2. SDG 7: Affordable and Clean Energy: Enhancing the portability, system reliability, user interface friendliness, and app usage rate of bicycles, while the use of electric bicycles can generate renewable energy. Creating a shared bicycle system driven by renewable energy can further promote sustainable transportation development.
3. SDG 11: Sustainable Cities and Communities: Transforming kinetic energy into sustainable electric bicycles, promoting eco-friendly and economically viable urban transport, advocating for bicycle-friendly urban infrastructure, and encouraging multi-functional urban planning are key to making public bicycles a primary mode of transportation.
4. SDG 13: Climate Action: Raising public awareness of low-carbon transport options, achieving low carbon emissions through riding electric bicycles, focusing on advanced bicycle-sharing systems that actively promote carbon reduction, and enhancing users' sense of environmental responsibility are critical strategies to bridge the gap between net-zero emissions and public bicycle strategies.

5.Conclusion & Future Work

This study has established a visionary perspective on the transformative potential of e-bikes within urban mobility, suggesting a path towards sustainable, efficient, and net-zero emission urban environments through speculative design and data-driven innovation. It has demonstrated that integrating advanced technologies and user-centric design into public bike systems can significantly enhance user experience and contribute to environmental goals. Future research should focus on expanding these initiatives to other urban areas, refining technology integration, and exploring the socio-economic impacts of expanded e-bike use. By continuing to align technological innovation with sustainability goals, e-bikes can play a pivotal role in reshaping urban transportation landscapes.

Leveraging advancements in big data analytics holds considerable promise for enhancing the functionality of public bike-sharing services like YouBike. Through meticulous collection and analysis of voluminous user data, operators can fine-tune bike distribution strategies, proactively manage maintenance, and heighten the user experience. A marriage of speculative design with rich, narrative-like thick data allows for an enriched comprehension of user behavior and predilections. This innovative approach informs the crafting of visionary strategies that are attuned to and shape the evolving landscapes of user experiences. The integration of YouBike within Taiwan's transportation matrix is a strategic move that propels the nation towards its net-zero emission targets while dovetailing with the global Sustainable Development Goals. This integration offers an eco-friendly transit alternative and advances the creation of sustainable urban communities. The pivotal role of e-bikes in the evolution of sustainable urban mobility is undeniable. Beyond their efficacy as a mode of transit, they substantially contribute to alleviating urban traffic and ameliorating air quality. Research on the functioning of YouBike is invaluable in shaping urban transport planning and policymaking. Insights into user trends and preferences are instrumental for city planners in designing infrastructures and policies that cater to cyclists and promote broader sustainable transportation practices.

Prospective research avenues include cross-city comparative studies that analyze how local designs, cultural settings, and policy landscapes influence the operation and acceptance of bike-sharing systems. Further examining how e-bikes can be integrated with existing transportation networks could yield insights into effective strategies for reducing urban carbon emissions. Conducting long-term environmental impact studies of e-bikes will provide concrete data on their role in emission reduction efforts, thus aiding in policy-making for sustainable transportation. Ongoing innovation in e-bike technology, focusing on aspects like battery efficiency and connectivity, is crucial to address the dynamic demands of modern cities and environmental sustainability. Finally, understanding the socio-economic ramifications of bike-sharing systems will shine light on their capacity to deliver equitable urban mobility and guide the design of systems that are universally accessible.

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