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Spatial Design Considerations for a Sustainable Electric Vehicle Hub in Kuala Lumpur: A Malaysian Context

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ABSTRACT

Electric Vehicle (EV) infrastructure in Malaysia lacks proper spatial planning that ignores the complex multi-scalar relationships that integrate EV elements into the existing urban fabric. The objective of this study is to generate spatial design approaches for EV hubs that are efficient, effective and intra-operable with transport systems within the broader public and private sectors. As EV uptake continues to grow, there is a serious deficit of critical pre-conditions especially with respect to the effective deployment of a range of EV related facilities such as charging stations, battery swapping systems, and maintenance facilities which are critical and central to the achievement of the successful transition to electric mobility. The research establishes the spatial parameters required to enable the establishment of economically and environmentally sustainable EV hubs considering the Return of Investment (ROI), the support of the public sector and the partnership of the private sector. Looking at various components of the EV, the study also suggests how tackling the issues of spatial design can help remove some of the significant barriers to infrastructure and encourage the widespread use of EV technologies. Also, evaluation of spatial designs and integration of the EV system with other systems for the user experience of the EV users and the ICE users is conducted. Finally, this study hopes to lessen the ecological impact of EVs by integrating green building concepts and sustainable energy

INTRODUCTION

The Electric vehicles (EVs) are represented as modern vehicles which do not require fossil fuels in order to operate as they run on electricity instead. It includes electric motors which utilise batteries or fuel cells

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that receive power from any charging unit (Alanazi, 2023). Instead, they contain further refinement of the said spectrum which can include three (3) major categories such as Hybrid Electric Vehicles (HEVs), Plug-In Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs) (Lozanova, 2023).

HEVs systems make use of electric power and Internal Combustion Engine (ICE) at the same time with the purpose to increase the overall efficiency of the fuel consumed while providing additional support to the different working conditions of the user (Ahmad et al., 2022). There are examples of such products such as Ford Escape Hybrid, Honda Accord Hybrid or Toyota Prius, which run on electric and gasoline motors at the same time in order to improve either the efficiency or the overall performance. Unlike the most popular electric vehicles, which may rely only on one battery pack, PHEVs have a bigger battery pack and also an internal combustion engine or an ICE. The bigger battery allows a PHEV to travel in electric mode for a distance of about 20 to 50 miles. After the battery runs out, the electric motor along with the ICE kicks in allowing it to run on hybrid power. PHEVs can cut down on fuel and emissions on short distances and can qualify for better renewable sources (Daina et al., 2017). A terrific example of this technology can be seen in the Chevrolet Volt. It has an electric-only range of 53 miles, which is remarkable. BEVs are designed in a way to use only electricity as their source of power. According to Alanazi (2023), there will be no tailpipe emissions making it the most environmentally safe and friendly means of transportation. As with PHEVs and hybrids, they have the competitive advantage of turning over 90 percent of electric energy into movement, cutting down on energy and operational costs over ICEs (Ahmad et al., 2022). With the recent advancements in battery technology making greater ranges and quicker charging times achievable, BEVs will become widely available. One famous example of a BEV that many admire is the Tesla Model 3, which is a clear vision of a zero-emission vehicle era (IEA, 2023).

Electric vehicles (EVs) represent a major transition in the transportation sector as countries move toward cleaner and more sustainable technologies. This shift is especially relevant in Southeast Asia, where rapid urbanization and high population density are intensifying challenges such as traffic congestion, deteriorating air quality, and rising greenhouse-gas emissions (Chalermpong et al., 2025). These pressures make the adoption of EVs not only desirable but necessary, as they offer a pathway to reduce urban pollution, improve public health, and support long-term environmental resilience in the region (Alanazi, 2023).

Battery Technology in Electric Vehicle (EV)

Batteries are essential for storing electrical energy in Electric Vehicles (EVs). They function through reduction and oxidation reactions in cells, which are combined into modules and battery packs. The main types of batteries used in EVs are Lithium-ion (Li-ion), Nickel Metal Hydride (NiMH), Lead-acid, Sodium-ion, and Solid-state (Arun et al., 2022).

The Li-ion batteries have managed to remain popular because they are efficient (95-98%), persistent (at least 3000 cycles with 80% depth of discharge), and possess high energy density (100-150 Wh/kg) all of which are useful for EVs (Arun et al., 2022). The rapid recharge abilities are approximately 30-60 minutes for charging 80% (IEA, 2023). Other variants of the technology such as Li-Nickel-Cobalt-Aluminum Oxide (NCA) and Li-Nickel Manganese Cobalt oxide (NMC) which contain cobalt on their cathodes have been known to improve the characteristics of the batteries (Ahmed & Maraz, 2023). Talking about batteries, the common type of battery might be Li-ion in most EVs, scooters and motorcycles, let alone high-end electric scooters. Such vehicles that most commonly employ li-ion batteries are the Tesla cars like Model S, Model M, Model 3, and Nissan Leaf and Hyundai Kona Electric for example (IEA, 2023) The use of Level 2 chargers and DC rapid chargers (Level 3) also match usage in EV charging points well (Acharige et al., 2023).

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NiMH batteries, though less efficient (72-78%) and shorter-lived (500 cycles at 100% discharge), are effective in low temperatures (-20°C to -40°C) and still used in some EVs (Ahmad et al., 2022). The Lead acidic cells can provide about 35 Wh/kg of energy but are hardly used in automobiles except for the auxiliary systems because of their short lifespan (IEA, 2023). In general, these batteries take about two to six (6) hours of charging time which is relatively more than Li-ion batteries. NiMH batteries have found their application in the first hybrid vehicles and in some low powered EVs for the reason of low cost and a fair amount of energy density. In older hybrid vehicles like Toyota's Prius, these batteries are more commonly seen but they are not in most two wheeled scooters and motorcycles because of their size and weight (Arun et al., 2022). The levels applicable in connection with the usage within the EV charging stations are Level 1 (household) and Level 2 (public) charger.

Sodium-ion batteries are cheaper and greener, work better at low temperatures and last longer, but are less energy dense than Li-ion (IEA, 2023). Solid-state batteries should have a higher energy density, more compact size, and greater numbers of cycles, and they should disrupt the EV industry within a decade (Arun et al., 2022). Sodium-ion batteries are expected to be used in small size low-cost EVs and might also be usable in commuter bicycles having short range (Arun et al., 2022). The compatibility of usage in EV charging stations is supported for Level 1, Level 2 chargers, and might have potential for DC fast charging with further development.

Problem Statement

The lack of EV infrastructure in Malaysia is becoming increasingly serious, as the current number of charging stations is unable to keep pace with rising EV adoption. A lack of adequate charging facilities could deter potential buyers of EVs thus slow down the uptake of electric vehicles, as noted by Malaysian Investment Development Authority (Malaysia Investment Development Authority, 2021). Filling station location and availability or ease of access, popularly termed as 'range anxiety', hinders consumers' willingness to share the fear of switching to electric vehicles. Due to insufficient charging infrastructure, many EV owners may face challenges when taking long trips or commuting. Without accessible and well-distributed charging stations, the practicality and benefits of EV technology are significantly reduced. The different standards and speeds for charging add to the complexities of the EV infrastructure. In an ideal situation, various models of EV might require level 1, level 2 or DC fast chargers that take less time to charge the devices fully (Daina et al., 2017). The occasional unavailability of these chargers due to compatibility conflicts can make the user experience the opposite and thus discourage the uptake of EVs. To enhance the adoption of electric vehicles, the country should seek to build a comprehensive and robust EV ecosystem including charging infrastructure, policies favourable for EVs, and workforce reskilling as measures to help in the reduction of greenhouse gas emissions and climate change. This is in line with The Twelfth Malaysia Plan, covering the years from 2021 to 2025, which seeks to achieve net zero greenhouse gas (GHG).

The web of life for the EVs industry in Malaysia has a crucial concern to first address and that is to formulate and design an all-encompassing EV ecosystem that will be fit for the country. Although there is an aspiration to make Malaysia an EV hotspot in the region, the current strategy is insufficient as it fails to foresee or grasp the requirements in the areas of producing, developing, or introducing the electric vehicles (Kresnawan et al., 2022). The lack of progressive proposals concerning the integration of any roles including but not limited to battery, electric drivetrains and sustainable strategies also stifles the growth of the industry. Also, issues like assuring the safety of work and compliance with international requirements points to a well-structured system that contains safe handling of high-voltage parts and regulatory procedures (Acharige et al., 2023). A few essential steps include creating clear objectives and strategies for the sustainability aspects directed at EVs, updating the program and space according to the trends of the industry, and developing the policies based on fostering innovation to create enough strength in the

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ecosystem that is expected to drive the changing of Malaysia's mobility to electric vehicles (Kresnawan et al., 2022).

The lack of necessary components for BEVs seems to be a most notable hindrance to the manufacturing and prevalence of electric vehicles. The difficulty in the supply is exacerbated by the increasing need for fully developed battery technologies, which are mostly lithium-ion due to their strong dependency on Lithium, cobalt, nickel, graphite and rare earth elements (IEA, 2023). The supply chain limitations are not only related to the supply and manufacture of these elements, but also reflect the volatility in the prices elicited by micrometric economic shocks contributing to factors such as BEVs, Consumer Electronics, and energy systems along with geopolitical reasons (Ahmed & Maraz, 2023). Moreover, there is also a time lag in the production of these materials due to the restrictions that live in the capacity level needed. These issues are telling as there has been a cut off to the supply chain due to requirement of high purity materials that best fit the requirements of the batteries. Widening the sources for the materials, funding in recovery and recycling technologies, and encouraging responsible supply chain practices along with research expansion for alternatives in battery composition will therefore be of help (Kalmykova, 2018).

Research Aim

The aim of this research is to investigate the spatial design, infrastructural, and environmental considerations required for the development of sustainable electric vehicle (EV) hubs in Kuala Lumpur within a Malaysian context. The study seeks to understand how spatial planning can support EV adoption while enhancing environmental sustainability, user experience, and integration with existing urban mobility systems.

Research Objectives

To achieve this aim, the study is guided by several objectives. These include assessing the current state and growth potential of electric vehicle (EV) adoption in Kuala Lumpur, evaluating key environmental considerations such as energy demand and emissions in the planning of EV hubs, and identifying the physical, spatial, and technical requirements necessary for establishing an effective and integrated EV ecosystem.

Research Question

This study is guided by the following research questions. First, how do electric vehicles (EVs) influence urban mobility patterns in Kuala Lumpur? Second, how do environmental and sustainability considerations shape the planning and design of EV hubs in an urban Malaysian context? Third, what spatial and infrastructural requirements are necessary to support a comprehensive and future-ready EV ecosystem?

Hypothesis

The spatial design features implemented in EV hubs significantly influence user satisfaction and adoption rates in the Malaysia context. However, the extent of this influence may vary depending on factors such as cultural preferences, infrastructure accessibility, and socioeconomic considerations.

Significance of the Study

The significance of this study lies in its potential to inform the development of EV infrastructure and training programs in Kuala Lumpur. By identifying spatial requirements and environmental considerations,

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the research can contribute to the creation of more sustainable and effective EV hubs, while also supporting the growth of a skilled workforce capable of meeting industry demands.

Creating sustainable EV hubs involves carefully planning the layout of infrastructure to accommodate electric vehicles effectively. This includes considering challenges and opportunities of electric vehicles. For example, urban areas may struggle with limited space for charging stations, while rural areas may lack access to electricity. EV infrastructure, new EV ecosystem and environmental considerations are crucial, to support EV hub adoption while reducing environmental harm and promoting economic growth.

Limitation

This study is subject to several limitations related to data availability, policy context, environmental assessment, and technological change. The analysis relies on accurate and current data on infrastructure, urban planning, and environmental conditions, which may be incomplete or inconsistent in the Malaysian context, potentially affecting the precision of the findings. In addition, EV-related policies and regulatory frameworks in Malaysia are relatively recent and still evolving, and shifts in government incentives or regulations may influence the feasibility and effectiveness of the proposed spatial design recommendations. Although environmental impacts are considered, the study may not capture all site-specific ecological effects of EV hub development, highlighting the need for detailed local environmental assessments. Furthermore, the rapid pace of EV technological advancement presents challenges for Malaysia in terms of infrastructure readiness, ecosystem development, and environmental management, which may constrain the applicability of the study's recommendations over time.

LITERATURE REVIEW

Introduction

This section seeks to tackle the comprehensive review by studying a literature review of the issues regarding EV charging infrastructure, methods, and practices. The section presents the different types of chargers that are crucial for the use and deployment of EVs. The section also details the mainstream practices of charging vehicles that include charging through a cable, charging without a cable, and changing batteries. This literature review covers the principle of circular economy theory towards closed-loop battery recycling and highlights key EV policies in Malaysia while offering a foundation in order to understand the challenges and providing design parameters for a sustainable EV hub.

Electric Vehicles Charging Levels and Modes

EVs enable cities for charging/discharging at varying levels depending on operational needs. However, the absence of standardised charging levels and modes needs to be addressed if EVs are to gain mass adoption. The fact that most modern plug-in EVs are working with a battery design that incorporates a high-power battery pack, battery management systems, various voltage regulating converters, controllers, and drive inverters is astounding (Arun et al., 2022). There are onboard and offboard EV chargers as well as unidirectional and bidirectional chargers. Primarily there are three (3) aspects which can be classified as charging methods: conductive, inductive (wireless) and battery swapping of vehicles. Conductive charging, which involves plugging the car into the power network, is the most used charging method for commercial electric vehicles. Conductive chargers are classified into three (3) levels (Level 1 to Level 3) based on the Society of Automotive Engineer (SAE) J1772 standard and into four (4) modes (mode one [1] to mode four [4]) according to the IEC 61851-1 standard (Acharige et al., 2023). In other words, three (3) types of

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wireless charging exist: capacitive, inductive, and resonant induction, which are supplied power without physical connections through magnetic fields between the sources and the receiving devices (IEC, 2017).

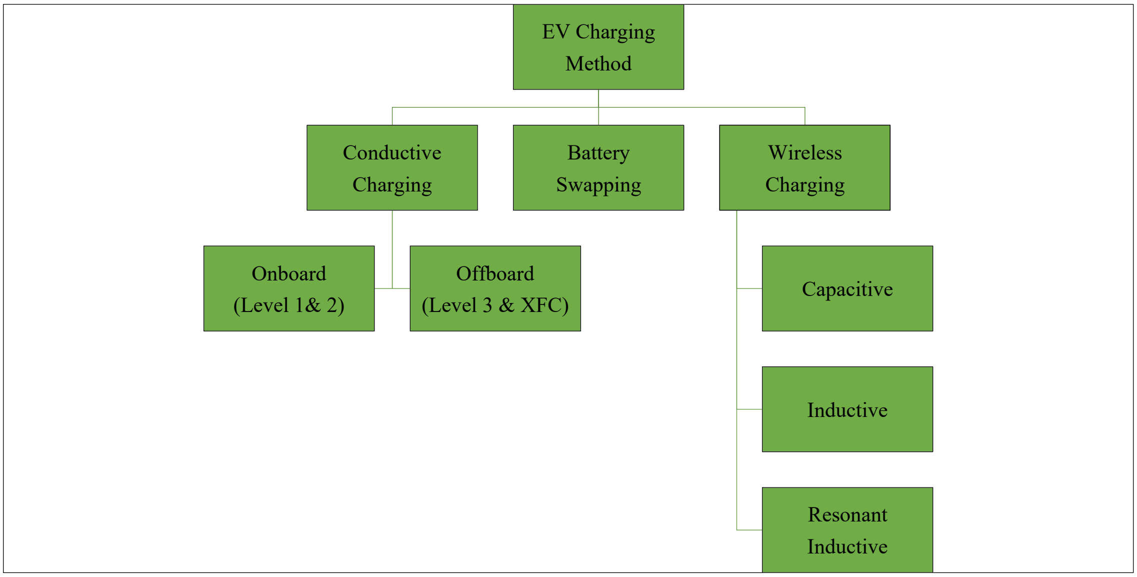

Fig. 1. Electric Vehicle Charging Methods

Source: Acharige (2022)

Charging Levels

Level 1 charging which is using a 120V AC power supply input through a single phase is the slowest and supplies a maximum of 1.92kW. It is most suitable for the household needs as it only takes about 11 to 36 hours to completely charge a battery ranging from 16 to 50kWh even without the additional infrastructure (PNW, 2022). Level 2 charging on the other hand is much faster as it is able to supply around 19.2 kW power via 208 to 240 Volts AC Power supply (PNW, 2022). It is quite common for both households and wider public facilities where a 30-50 kWh battery can be charged in approximately two (2) to three (3) hours. Europe primarily utilises IEC 62196-2 for level 1 and 2 connectors while the USA has shifted towards Ford's SAE J1772 and Tesla Superchargers (SI, 2017). On the other side, Level 3 charging, also known as Direct current fast charging, supplies a total of 20 to 350 kW of power. This is provided through 300 to 800V power supply. It employs off board chargers connected to the three-phase grid supply which allows reducing the total time taken for charging to between 0.2 to 0.5 hours. Some of the common connectors are Tesla Superchargers and CCS Combo 1. Extrema fast charging (XFC) exceeds the 350kW at 800 Vdc internal DC bus voltage and battery recharging times within approximately five (5) minutes. To achieve this kind of rapid recharge of batteries solid state transformers (SST), DC-DC converters can be used but are very expensive to install and operate as well (Daina et al., 2017).

Charging Modes

The different ways of charging an electric vehicle can be ascertained as per the International Electrotechnical Commission (IEC) for global acceptance (IEA, 2023). The first mode or mode one (1) entails basic charging alternating current with ordinary Socket. The current in all cases is limited to 8 A – 16 A value which is ideal for home use but with little protection. Mode two (2) charges while ensuring

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safety against electric shock hazard, all thanks to achieving the proper use of an in-cable control and protection device (IC-CPD) with a maximum power of 15.3 kW at 32 A which allows it to have a home charging system (Acharige et al., 2023). Mode three (3) employs dedicated Electric Vehicle Supply Equipment (EVSE) permanently installed and allows semi-fast mode charging which ranges from 60 kW to 120 kW for single and three-phase respectively. This mode supports communication between the vehicle and the electric power system grid, enabling smart charging mode four (4) comes second in the hierarchy when it comes to speed as it offers rapid charging using external devices as the battery charger, which are normally in excess of 150 kW and is common in public sites. This mode has more control, communication, and protection features allowing high current up to 400A (Daina et al., 2017).

Table 1. Comparison Of Different Electric Vehicle Charging Levels

Specification	Level 1	Level 2	Level 3	Extreme Fast Charging (XFC)
Charging Power	1.44 kW - 1,9 kW	3.1 kW - 19.2 kW	20 kW - 350 kW	>350 kW
Charger Type	Onboard - Slow Charging	Onboard - Semi-fast Charging	Offboard - Fast Charging	Offboard - Ultra-fast charging
Charge Location	Residential	Private and Commercial	Commercial	Commercial
Charging Time	200 km: +/- 20 hours	200 km: +/- 5 hours	80% of 200 km: +/- 30 min	Approximately 5 min with high energy density
Power Supply	12-/130 Vac, 12 A - 16 A, Single Phase	208/240 Vac, 12 A - 80 A, Single Phase/Split Phase	208/240 Vac & 300-800 Vdc, 250-500 A Three-Phase	1000 Vdc and above, 400 A and higher Polyphase
Supply Interface and Protection Type	Convenience Outlet (Breaker in Cable)	Dedicated EV supply equipment (Breaker in the cable and pilot function)	Dedicated EV supply equipment (communication & event monitoring between EV and charging station)	Dedicated EV supply equipment (communication & event monitoring between EV and charging station)
Standards	SAR J1772, IEC 62196-2, IEC 61851-22/23, GB/T 20234-2		IEC 61851-23/24 IEC 62196-3	IEC 62196 SAE J2836 & J2847/2

Source: Acharige et al. (2023)

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Table 2. Comparison of Different Charging Modes

Charge Mode	Phase	Current	Voltage	Power (Max)	Specific Connector
Mode 1	AC - 1 AC - 3	16 A	230-250 V 480 V	3.8 kW 7.6 kW	No
Mode 2	AC - 1 AC - 3	32 A	230-250 V 480 V	7.6 kW 15.3 kW	No
Mode 3	AC - 1 AC - 3	32-250 A	230-250 V 480 V	60 kW 120 kW	Yes
Mode 4	DC	250-400 A	600-1000 V	>150 kW	Yes

Source: Acharige et al. (2023)

Closed-Loop Recycling Battery of Circular Economy Theory

The theory of a Circular Economy works well with the understanding and practical application of Closed Loop Recycling. A circular economy is defined as an economic system that aims to eliminate waste and the constant use of resources, based on three (3) principles: designing out waste and pollution, keeping products and materials in use, and regenerating natural systems (Kirchherr et al., 2023). Closed-loop recycling is one (1) of the core principles that underpin a circular economy because it is the technique of recovering materials where they are reintegrated back into the production process in a never-ending, cumulative process, that enables the minimization of loss or wastage of materials (General Kinematics, 2018). In this way, the amount of virgin natural resources extracted is limited while biodegradable wastes are significantly curtailed through efficient material re-use and recycling. There is a dire necessity of closed-loop battery recycling because of the widespread adoption of lithium-ion and other battery designs that considerably undermine the environment (Hartley et al., 2025).

Battery recycling involves several practical steps with an aim of retrieving precious materials from used batteries. Managers determine the specific type of intersectionality used batteries on collection and take them from homes, factories, and even from other recycling plants (Hartley et al., 2025). Disassembling of these batteries entails dismantling them to remove their casings, electrodes, and electrolyte. The batteries that were collected in the previous stages are first grouped together based on their make-up, such as lithium per polymer lithium polymer, lead, nickel-cadmium, or nickel-metal hydride, before mechanical dissolution commences (Ahmed & Maraz, 2023). Fortunately, batteries have useful polymers and metals that can be reused. Crucial operations involved in this step include processing, cutting, and even milling. To then harvest metals like cobalt, lithium, and nickel; the first step using hydrometallurgy is done. During the physicochemical process that follows, the substance is dissolved and subsequently multiple methods are employed to assist with the separation. The metals that have been extracted need to undergo refining to be suitable for the creation of new batteries. All of the battery materials that can be used again will then be combined with newly created materials, therefore minimizing the amount of waste produced. Figure 2 represents the monetary flow patterns throughout the given cycle (Eddy, 2024).

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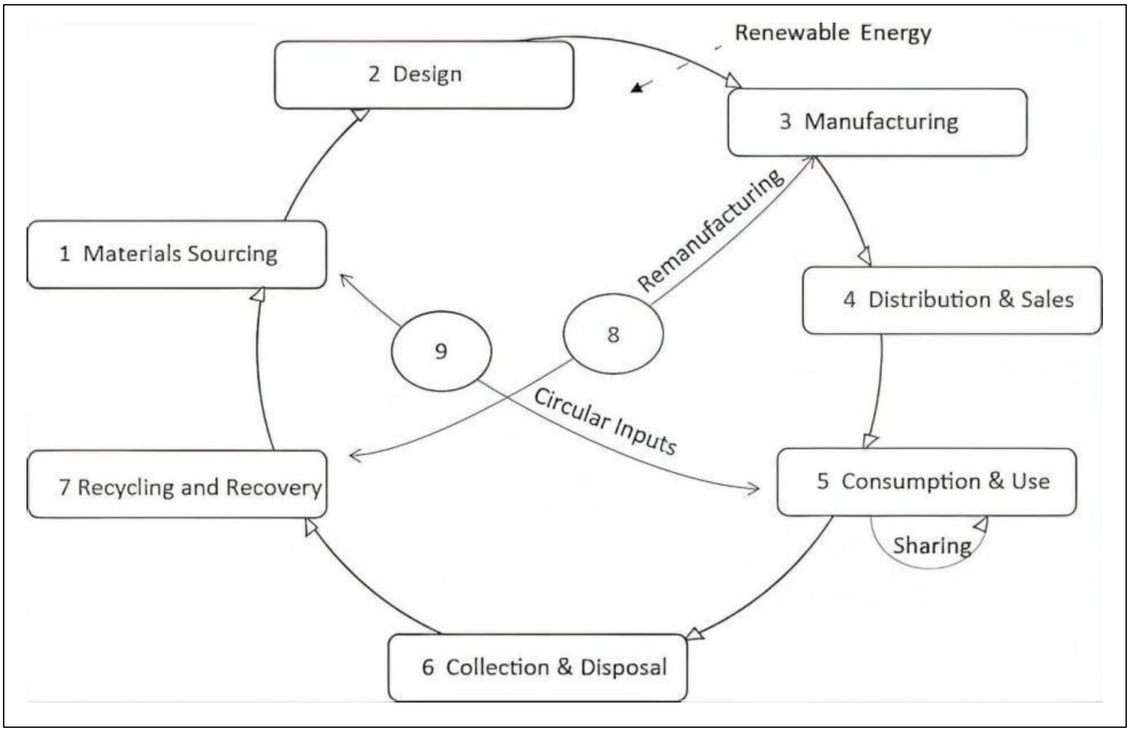

Fig. 2. Resource Flows Through a Value Chain in a Circular Economy

Source: Eddy (2024)

Key EV Policies in Malaysia

As part of its economic strategy framework, Malaysia provides tax incentives for EVs that include the waiver of road tax and personal charges accruable to the cost of charging infrastructure in the amount of 2,500 ringgit until after the year end of 2023 (MIDA, 2024) Additionally, within the context of its Low Carbon Mobility Blueprint, Malaysia has a target of installing 10,000 public charging stations for electric vehicles by the year 2025 (Nguyen, 2021) In the context of government administration power, there is a target of 10% of government fleets using BEVs in the next few years while a proportion of 50% is estimated between the years 2026-2030 (MIDA, 2024).

On the other hand, concerning the production tax incentives for the foreign owned companies, Malaysia Investment Development Authority (MIDA) emphasises on the restriction on any percentage investment limit in Malaysia in the subscribed local companies through the investment promotion agencies for the leasing of electric vehicles (MIDA, 2024).

EV Battery production in Malaysia

Malaysia has made significant strides in EV and battery production. In 2020, Honda began producing hybrid vehicle batteries in the country (Nair, 2019). Plans for an EV battery manufacturing hub were initiated through a Memorandum of Understanding (MoU) between Hong Seng Consolidated and EoCell. Samsung also announced development plans in Malaysia (Jennings, 2022). Semiconductor chips, crucial for battery production, are manufactured by companies like Fujitsu Semiconductor, Infineon, NXP,

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Renesas, and Texas Instruments, with Malaysia serving as a major production hub (Horowitz et al., 2017). Infineon is expanding further with a new chip production plant in Kulim Technology Park (MIDA, 2024).

Malaysia is also focusing on EV production. Honda manufactures HEVs, while Mercedes-Benz produces PHEVs (Roberts, 2021). Plans for BEV production is in progress through joint ventures involving Fieldman Group, Changan Automobile, Foxconn, and PTT BK (Roberts, 2021). While battery recycling remains in its early stages, these initiatives position Malaysia as a key player in Southeast Asia's growing EV sector (Fallin & Lee, 2022).

Table 3. EV Supply Chain in Four SEA Countries

Nodes in EV Supply Chain	Indonesia	Malaysia	Thailand	Vietnam
Mineral Resources				
EV Battery Production				
Battery Swapping				
Semiconductor Chips				
EV Production by types of vehicles: Motorbikes				
HEVs				
PHEVs				
BEVs				
Battery Recycling				
R&D Activities				
Notes:	In production			
	Planned			
	No announced plans as yet			

Source: Tham (2022)

Transit-Oriented Development (TOD) and Mobility-Oriented Development (MOD) Theory

Transit-Oriented Development (TOD) is a foundational urban planning theory that promotes compact, high-density, and mixed-use development centred around public transportation infrastructure. TOD seeks to reduce car dependency by creating walkable districts within a short radius of transit stations, enabling efficient access to housing, employment, and services through sustainable mobility modes. By integrating land use with rail and bus networks, TOD addresses major urban challenges such as traffic congestion, inefficient land consumption, and rising emissions (Suzuki et al, 2013). As Malaysian cities continue to expand their rail systems, TOD principles are increasingly viewed as essential for shaping low-carbon urban environments and improving access to mobility infrastructure (MIDA, 2020).

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Fig. 3. Transit-Oriented Development Concept

Source: Sharma (2024)

Building on TOD, the Mobility-Oriented Development (MOD) theory advances a more comprehensive and technology-adaptive model that integrates a wider range of mobility systems including electric vehicles (EVs), micromobility, shared mobility, drone logistics, and renewable-energy-based charging facilities. MOD positions mobility hubs not only as transit-oriented spaces but as multi-modal ecosystems that connect public transport with EV charging networks, battery-swapping zones, micromobility platforms, and autonomous delivery systems (IEA, 2023). International examples such as Sortimo Innovations Park in Germany and Tivoli Green City in Belgium demonstrate how MOD creates scalable, future-ready mobility nodes that combine clean energy, EV infrastructure, and active transport networks (Al-Thani et al., 2022). Within the Malaysian context, MOD provides a more suitable theoretical lens than TOD alone, as it aligns with national ambitions to integrate EV hubs, public transport, and emerging mobility technologies into a unified, sustainable mobility framework (EV Connection, 2023).

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Fig. 4. Case Study of Sortimo Innovations Park

Source: Str.ucture. (2024)

METHODOLOGY

This section will elaborate on the methodology designed to address the research questions and fulfil the research objectives. It encompasses the research design, data collection methods, and an in-depth analysis of the spatial design for sustainable EV hubs in Kuala Lumpur based on the Malaysia context. To provide a comprehensive understanding, the study employs qualitative approaches, specifically document analysis and observation, along with interviews. This section explores the intricacies of the data collection strategy in detail.

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Research Design

Table 4. Research Design Frameworks

	Research Questions	Research Objectives	Research Methodology	
To explore the spatial design, infrastructure, and environmental considerations necessary for establishing sustainable electric vehicle (EV) hubs in Kuala Lumpur, including the spatial needs for EV new ecosystems and practices to enhance sustainability while integrating EV infrastructure into the Malaysian context.	RQ1	RO1	RM1	**Spatial Design Considerations for a Sustainable Ev Hub in Kuala Lumpur Based on a Malaysian Context**
	How do electric vehicles (EVs) influence urban mobility patterns in Kuala Lumpur?	To assess the current state and growth potential of electric vehicle (EV) adoption in Kuala Lumpur.	A.Literature Review B. Interview C. Case Study	
	RQ2	RO2	RM2	
	How do environmental and sustainability considerations shape the planning and design of EV hubs in an urban Malaysian context?	To examine the environmental aspects in the planning process of EV hubs.mi	A.Articles & Theory B. Interview C. Government Policy.	
	RQ3	RO3	RM3	
	What spatial and infrastructural requirements are necessary to support a comprehensive and future-ready EV ecosystem?	To determine the physical and structural aspects that are necessary for the proper EV infrastructure as a new ecosystem.	A.Literature Review B. Interview C. Case Study	
	Section 1	Section 2	Section 3	

Source: Authors (2024)

The research design aligns each research question with appropriate qualitative methods. Literature review and document analysis were employed to examine EV adoption trends, infrastructure gaps, and policy frameworks in Kuala Lumpur. Case study analysis was used to evaluate spatial configurations, environmental strategies, and operational characteristics of selected EV hubs. Open-ended interviews complemented these methods by providing user-based insights into spatial usability, accessibility, and functional requirements. This triangulated approach strengthens the reliability of the findings and ensures consistency between the research objectives and methodological framework.

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Data Collection Procedure

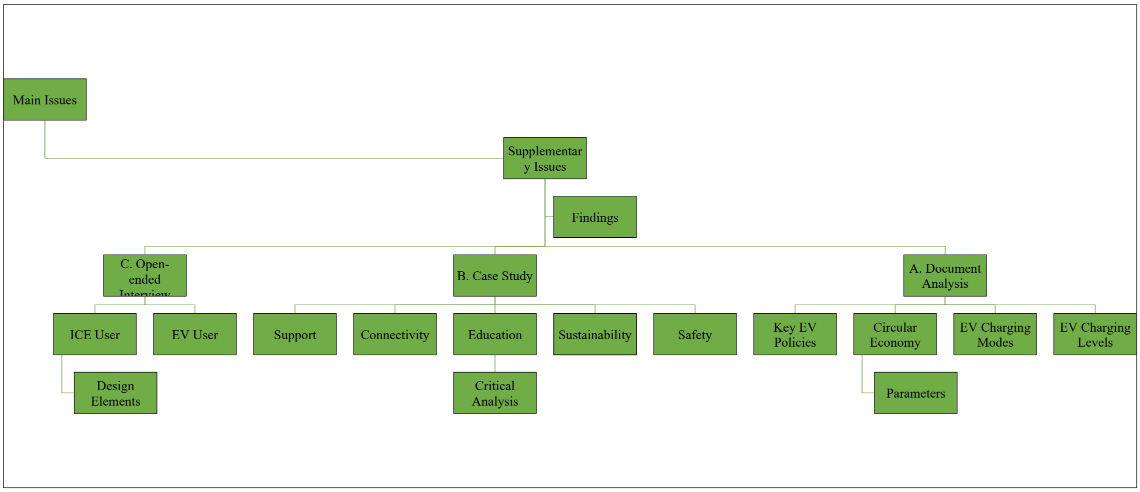

Fig. 5. Research Flow

Source: Authors (2024)

This research adopts a qualitative methodology comprising document analysis, case study analysis, and open-ended interviews to address the research objectives. Figure 5 illustrates the overall research flow, outlining the sequence of data collection and analysis processes. The methodology focuses on understanding spatial design strategies, infrastructure planning, environmental considerations, and policy frameworks relevant to the development of sustainable EV hubs in Kuala Lumpur.

RESULTS AND DISCUSSION

This section presents and discusses the findings derived from document analysis, case study evaluation, and open-ended interviews. The results are analysed in relation to the research objectives, focusing on spatial design considerations, environmental sustainability, and infrastructural integration of EV hubs in Kuala Lumpur. By synthesising empirical findings with theoretical frameworks such as Mobility-Oriented Development (MOD), this discussion highlights how spatial planning influences user experience, system efficiency, and the long-term viability of EV infrastructure in an urban Malaysian context.

Analysis of Document Findings

The document analysis was based on national policy documents, urban planning guidelines, academic journals, and industry reports related to electric vehicle infrastructure, sustainability, and mobility planning in Malaysia. Key sources included government publications from the MIDA, EV infrastructure guidelines, and peer-reviewed academic literature. The design parameters presented in Table 5 were derived through thematic coding of these documents, focusing on safety, sustainability, ecosystem integration, and connectivity.

Table 5. Design Parameter of Document Analysis

No	Design Feature	Design Element	Design Parameter
1	Flood Resilience Design	Ensuring the hub is designed to handle potential flooding, especially given the climate of Kuala Lumpur.	Safety
2	Safety Features (Emergency)	Emergency protocols, fire extinguishers, and first-aid kits to ensure the safety of EV users and staff during operation.	Safety
3	Waste Management Systems	Implementing efficient waste management systems for recyclable materials and electronic waste from used batteries.	Sustainability
4	Energy Storage Solutions	Implementing battery storage systems to store energy from renewable sources and use it when needed to stabilise power supply.	Sustainability
5	Electric Vehicle Parking	Sufficient parking spaces for electric vehicles to allow for smooth operation and prevent congestion.	Ecosystem
6	Green Spaces and Landscaping	Incorporating green areas, trees, and plant life around the hub to enhance environmental quality and user experience.	Ecosystem
7	Charging Infrastructure	Availability of Level 1, 2, and 3 chargers, ensuring fast and efficient charging options.	Connectivity
8	Public Transport Accessibility	The hub's proximity and integration with LRT, MRT, and bus systems to allow for easy access and reduce car dependence.	Connectivity
9	Battery Swapping Facilities	Areas designed for quick battery replacement, reducing downtime for EVs and providing an alternative to traditional charging.	Support
10	Smart Charging Management	A digital platform to manage and optimise charging times, reduce grid load, and provide real-time information to users.	Support

Source: Authors (2024)

The study of the document findings identifies key design features as initial concepts. Factors come together in order to achieve certain design elements, and thus, precise design parameters are formed which may assist in developing the potential of spatial planning for an environmentally friendly EV hub in the capital of Malaysia, in this case Kuala Lumpur.

Analysis of Case Study

The case studies were selected based on their relevance to EV infrastructure deployment, spatial integration with urban mobility networks, and sustainability initiatives. Selection criteria included location within urban areas, availability of EV charging facilities, integration with public transport, and the presence of user-oriented design features. The design parameters and spatial elements analysed in Table 6 were derived from on-site observations, layout analysis, and secondary data sources. These case studies provide comparative insights into existing practices and inform the spatial design recommendations proposed in this research.

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Table 6. Spatial Configuration of Case Study Analysis

No	Design Parameter	Design Element	Spatial Configuration Analysis
1	Safety	Safety Measures	Many EV charging stations in Malaysia adhere to standard parking space sizes, typically ranging from 2.4 metres to 2.7 metres in width and 5.0 metres in length. These sizes accommodate most passenger vehicles, ensuring that electric cars can park comfortably while charging without blocking adjacent spaces or pedestrian pathways.  Fig. 6. TNB Electron Size Parking Source: Authors (2024)
2	Sustainability	Long-Term Environmental Impact	Current EV stations in many countries started to focus on integrating solar panels and renewable energy sources where possible, aiming for a more sustainable infrastructure. However, EV stations in Malaysia still rely on conventional electricity. There is potential for greater carbon-neutral strategies, such as waste reduction and incorporating more green technology.  Fig. 7. Johor Premium Outlet DC Handal Hub Source: Authors (2024)

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No	Design Parameter	Design Element	Spatial Configuration Analysis
3	Ecosystem	Digital Ecosystems Education and Engagement	Some EV stations, particularly in urban areas, feature informational signage about EV technology. However, educational facilities are still limited. Developing digital ecosystems would help users to learn about sustainable practices, EV benefits and vehicle maintenance.  Fig. 8. Digital application by JomCharge Source: Wong (2024)
4	Connectivity	Integration with Urban Mobility Networks	Many EV stations in Malaysia are located near major roads or shopping centres, with some proximity to public transportation like LRT stations. There is room for better integration, ensuring smooth pedestrian access from public transport to the stations, which would encourage more people to use EVs as part of their daily commute.  Fig. 9. EV Charging Stations Source: EV Connection (2023)
5	Support	Open Area and Size	Existing EV stations often have limited space, with charging stations located in busy areas that may not have enough parking or room during peak times. Increasing the capacity of these stations, providing seating, shaded areas, and sufficient parking slots would improve the experience for users, especially for those waiting while their vehicle charges.

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No	Design Parameter	Design Element	Spatial Configuration Analysis
			 Fig. 10. TNB Electron Parking Area Source: Authors (2024)

Source: Authors (2024)

The Spatial Configuration considers the layout design of the EV hub and its implications on users' movement and behaviours. Charging facilities are suitably located to prevent overcrowding and displacement to areas away from pedestrian traffic for ease of movement. Different zones around the space such as charging points, rest areas and learning spaces are provided with signposts for easy access. The hub is accessible as it has good links with the nearby roads, public transportation and social infrastructure. The users are able to rest during the charging process as social and rest areas are equipped with seats and shading. In general, the design guarantees the effectiveness, interest and usability of the hub.

Open-ended Interview

Open-ended interviews were conducted with two (2) respondents: one (1) existing EV user and one (1) internal combustion engine (ICE) vehicle user who expressed interest in transitioning to electric mobility. The respondents were selected based on their familiarity with urban travel in Kuala Lumpur and their exposure to EV infrastructure. Although the sample size is limited, the interviews were exploratory in nature and intended to provide qualitative insights rather than statistical generalisation. This approach is appropriate for understanding user perceptions, experiential challenges, and expectations related to EV hub design at an early research stage.

Participant A (EV User's Experience): This participant provides detailed information concerning their electric car experience while focusing on the infrastructural needs, convenience and level of satisfaction with the existing EV hubs.

Participant B (ICE User's Transition): Describes the transition effects that come about when one moves from an ICE car to an EV, including the challenges and the views regarding the infrastructure of the EV hubs and anticipation of the future EV hubs.

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Table 7. Open-ended Interview Design Element Analysis

No	Interview Questions	EV User	ICE User	Design Element Analysis
1	How do you feel about the current EV infrastructure?	Not too bad but the expansion of numbers and fast charging should be considered.	Not sure enough of what potential EVs in Malaysia.	EV users want more charging stations, while ICE users are cautious due to uncertainty.
2	What are your main concerns regarding EV infrastructure?	Availability of charging stations and waiting times.	The reliability of charging stations and lack of knowledge about EVs.	EV users express concern over convenience, while ICE users highlight a lack of awareness.
3	Do you think EV infrastructure is adequate for your needs?	No, especially in rural areas.	Obviously think the need of EV infrastructure is not enough	Both EV users and ICE users agree that more infrastructure is needed, particularly in underserved areas.
4	How would you improve the current EV hub designs?	More fast charging stations, better layout for smooth flow, introduce new technology for better EV ecosystem and clearer signage.	Perhaps more clear information on where to find chargers, especially in public spaces.	EV users emphasise fast charging, emphasise on design flow, introduce a new ecosystem of EV and clear signage, while ICE users seek clearer information.
5	What do you think could make an EV hub more user-friendly?	A combination of charging, rest areas, and accessible amenities like food and seating.	Clear directions and more user-friendly locations, especially near public transport.	EV users want more amenities, while ICE users seek better locations and accessibility.
6	What kind of space/ programs would you like to see in an EV hub?	Workshops on EV technology, community spaces for socialising and sharing tips.	More guidance on how to switch to an EV and financial incentives for doing so	EV users want a community-oriented hub, while ICE users seek educational programs and incentives.
7	How important is it for the EV hub to be located near public transport?	Very important, it would make it easier to travel while my EV charges.	It is key for convenience, especially if there is a transition period for ICE users to switch to an EV.	Both EV users and ICE users see the importance of connectivity with public transport.
8	How do you think EV hubs could evolve in the future to better serve users?	More integration with renewable energy sources like solar panels and fast-charging tech.	I think better incentives, such as discounts for EV users or easier financing options, would help.	EV users are looking for sustainable energy integration, while ICE users are more focused on financial incentives and transition support.
9	Would you like to see more multi-functional spaces in EV hubs, such as places for work or recreation?	Yes, it would be helpful to have co-working spaces or cafes to use while waiting for the car to charge.	Perhaps, if there is an opportunity to learn more about EVs or meet others transitioning from ICE.	EV users favour a more dynamic and productive environment, while ICE users are open to multi-functional spaces that support learning and social interaction.
10	What could be added to EV hubs that would encourage more people to switch from ICE vehicles to EVs?	Incentives like free charging sessions or financial assistance to reduce the upfront cost of EVs	More information about the long-term savings and environmental benefits of EVs.	EV users suggest direct incentives, while ICE users require more education and awareness about the advantages of EVs.

Source: Authors (2024)

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Design Findings

Spatial configuration inspired by Mobility Oriented Development (MOD)

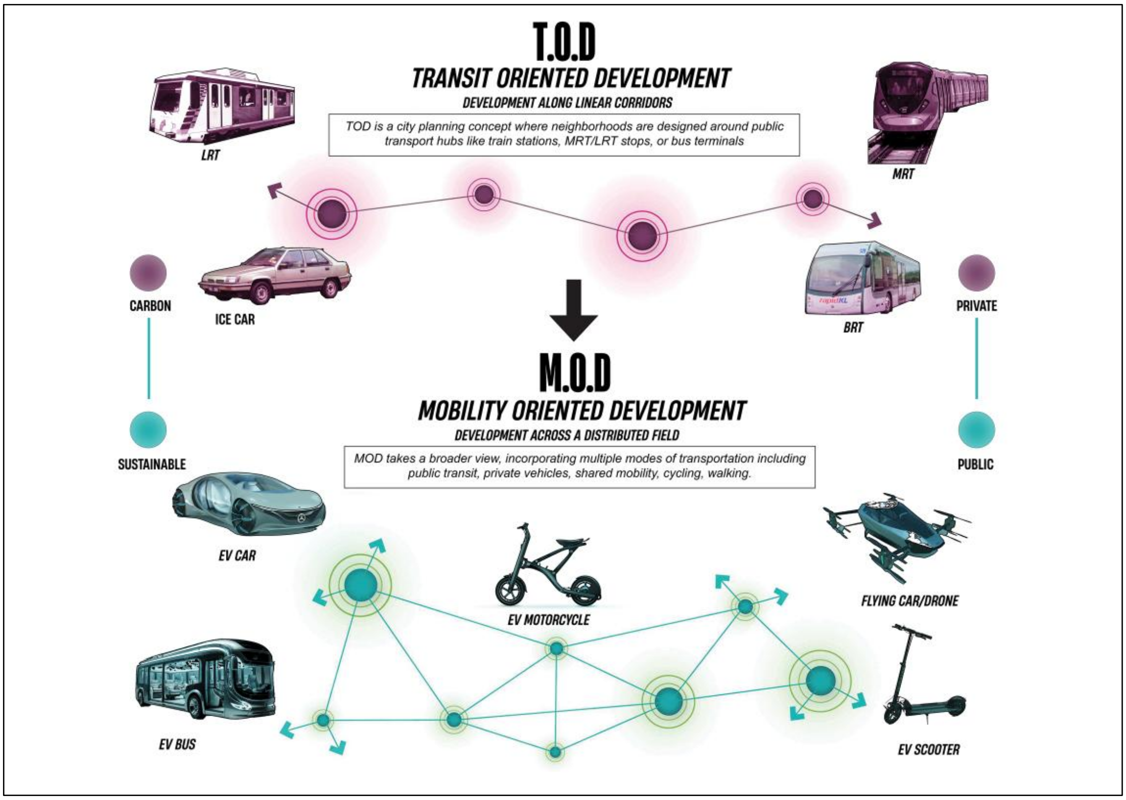

Fig. 11. Mobility Oriented Development (MOD)

Source: Authors (2024)

The spatial configuration of the proposed EV hub is shaped by the MOD framework, which expands the principles of TOD by integrating electric vehicles, public transport, micromobility and emerging logistics technologies into a single mobility ecosystem.

Based on this framework, the spatial design adopts a hierarchical, multi-level arrangement that separates functions according to accessibility, safety and operational needs. The upper level accommodates skyport platforms, drone-based battery delivery systems, and elevated pedestrian link bridges, enabling seamless integration with Mass Rapid Transit (MRT) and Light Rail Transit (LRT) stations while reducing ground-level congestion. The mid-level focuses on micromobility services, including e-bike and e-scooter parking, battery-swapping zones, and user-oriented facilities such as lounges and digital information centres, supporting short-distance travel and public engagement.

The ground level hosts the core EV charging activities, including multi-vehicle fast-charging lanes, wireless charging zones, and maintenance areas designed for efficient vehicular circulation. This spatial configuration enhances connectivity across all transport modes, minimises user conflict through functional clustering, and creates a flexible structure that can scale with future EV demand. By applying the MOD

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approach, the EV hub operates not as an isolated facility but as a fully integrated mobility node that supports Malaysia's transition toward a more sustainable, multi-modal, and future-ready transportation network.

Public Transport and Micromobility Integration Strategies

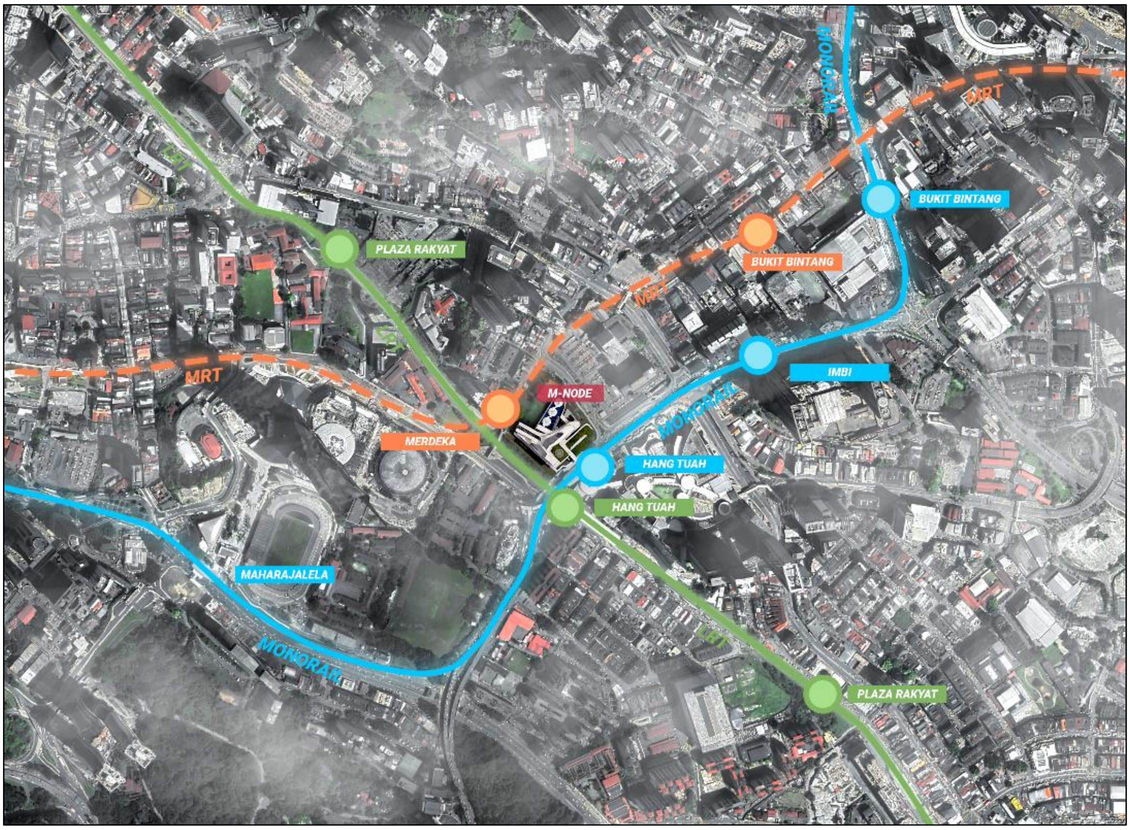

Fig. 12. Public Transport and Micromobility Integration Strategies in Bukit Bintang City Centre (BBCC), Kuala Lumpur

Source: Authors (2024)

The Bukit Bintang City Centre (BBCC) is one (1) of the examples that presents a highly strategic location for developing an integrated public transport–micromobility network in Kuala Lumpur due to its dense concentration of rail, monorail, and urban activity nodes. The study area is directly served by multiple high-capacity transit lines, including the MRT Kajang Line (Bukit Bintang, Merdeka, and Plaza Rakyat stations) and the KL Monorail (Hang Tuah, Imbi, and Maharajalela stations), forming a continuous mobility spine that supports high passenger throughput across Kuala Lumpur's core (MRT Corporation, 2023). The proximity of these stations within a walkable radius enables MIDA seamless transit interchange, reinforcing the principles of integrated urban mobility proposed under TOD, where land-use density, pedestrian connectivity, and public transport infrastructure converge to support low-carbon travel behaviour (Al-Thani et al., 2022). This multimodal connectivity positions BBCC as a suitable site for embedding MOD features, such as EV hubs, micromobility docking areas, and shared-mobility platforms, which align with Malaysia's vision for a connected, electrified transport ecosystem.

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Micromobility integration within the BBCC area further strengthens the last-mile connectivity between major rail stations and the surrounding commercial, institutional, and recreational clusters. The dense street network and short block lengths around Jalan Hang Tuah, Jalan Pudu, and Jalan Bukit Bintang create favourable conditions for e-scooter lanes, cycling tracks, and shared-mobility corridors, allowing riders to move efficiently between MRT, monorail, and EV hub infrastructure. International research demonstrates that integrating micromobility within high-density transit districts significantly increases station accessibility and reduces reliance on private vehicles (Shaheen et al, 2019). Applying these strategies to BBCC, the proposed EV hub (M-NODE) can function as a central interchange node that consolidates micromobility parking, battery-swapping facilities, and EV charging platforms while serving as a pedestrian gateway linking the Merdeka 118 precinct, Hang Tuah corridor, and Bukit Bintang commercial zone. This integrated approach aligns with MOD principles that emphasise the merging of EV infrastructure, micromobility services, and public transport to create a seamless, multi-modal mobility ecosystem capable of supporting Kuala Lumpur's transition toward sustainable urban mobility (IEA, 2023).

CONCLUSION

This paper concludes with a thorough investigation of the planning and effects of transformational spaces for Malaysian EV users. Through in-depth case studies, thorough literature assessments, and perceptive interviews, the complex relationship between user behaviour, spatial design, and the uptake of EV infrastructure is made clear.

Consider it as a starting point for upcoming urban initiatives that go beyond the initial networks of EV stations as we approach the end. In order to change Malaysia's urban and rural transportation environments, it urges communities, private stakeholders, urban planners, and politicians to collaborate. Through component integration and the construction of environments that are both practical and transformative, this plan encourages the development of a large, sustainable, and inclusive EV ecosystem.

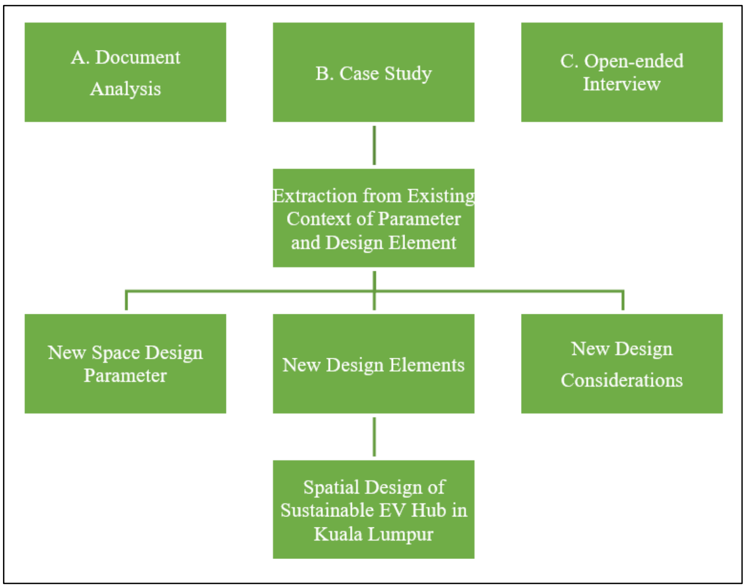

Fig. 13. Diagram of Findings

Source: Authors (2024)

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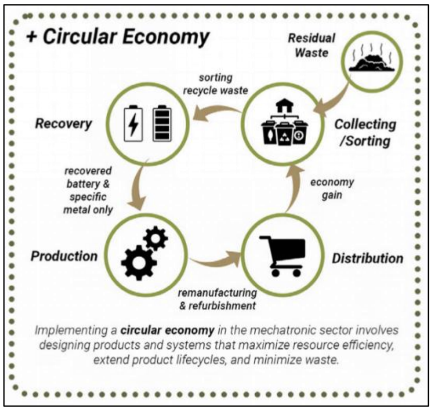
Spatial Design Recommendations

The spatial design recommendations presented in Table 8 are derived from the synthesis of document analysis, case study findings, and interview insights. These recommendations aim to enhance safety, sustainability, connectivity, and user experience within EV hubs. By addressing both functional and experiential aspects, the proposed design strategies support the development of inclusive, adaptable, and future-ready EV hubs that align with Malaysia's urban and environmental goals.

Table 8. Recommendation of Spatial Design for Sustainable EV Hub

No	Space Design Parameter	Design Elements	Design Consideration	Target Group
1	Safety & Sustainability	Flood Resilience, Safety Features, Waste Management	Design for flood resilience, incorporate emergency protocols, fire extinguishers, first-aid kits, and efficient waste management systems for recyclable materials.  Fig. 14. Waste-To-Energy Idea towards Circular Economy Source: Authors (2024)	All Users
2	Sustainability	Energy Storage Solutions, Green Roof, Green Spaces	Integrate renewable energy sources (e.g., solar power), battery storage systems, and green spaces to enhance environmental quality and sustainability.  Fig. 15. Sortimo Innovations Park Green Design Source: LAPP (2020)	EV Users and Sustainability Advocates

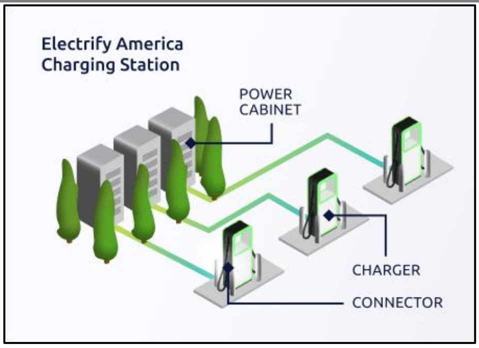
<table>
<tr><th>No</th><th>Space Design Parameter</th><th>Design Elements</th><th>Design Consideration</th><th>Target Group</th></tr>
<tr><td></td><td></td><td></td><td>

Fig. 16. Electrify America Charging Station
Source: Electrify Canada (2024)</td><td></td></tr>
<tr><td>3</td><td>Ecosystem</td><td>Digital Ecosystems, EV Parking</td><td>Develop digital platforms for education on EVs, ensure adequate EV parking and traffic, and enhance the ecosystem with educational signage.

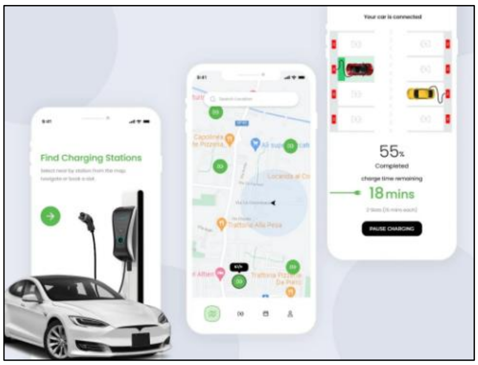

Fig. 17. Provide adequate EV Parking
Source: Authors (2024)


Fig. 18. Enhance EV Ecosystem by Apps
Source: Prismetric (2024)</td><td>EV Users and Potential EV Adopters</td></tr>
<tr><td>4</td><td>Connectivity & Support</td><td>Charging Infrastructure, Public</td><td>Provide multiple levels of charging stations, integrate with LRT, MRT, and bus networks, and ensure the hub is easily accessible and connected to urban mobility.</td><td>All Users</td></tr>
</table>

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No	Space Design Parameter	Design Elements	Design Consideration	Target Group
		Transport Access	 Fig19. Integrate with potential Public Transportation Source: Authors (2024)	
5	Support & Multi-functionality	Battery Swapping, Smart Charging, Multi-Functional Spaces	Provide battery swapping facilities, financial incentives, implement smart charging systems, and create multi-functional spaces like cafes, workshops, and co-working areas.  Figure 20. Battery Swapping Station Space Source: Air (2024)  Figure 21. Lounge Area as Waiting Point Source: Krisher (2024)	EV Users, Stakeholders and ICE Users Transitioning to EV

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No	Space Design Parameter	Design Elements	Design Consideration	Target Group
			 Figure 22. Cafe while charging EV Car Source: LAPP (2020)	

Source: Authors (2024)

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

Muhammad Haziq Yahya conceptualised the research idea, designed the methodology, conducted the investigation, collected and analysed the data, and drafted the manuscript. Azri Ibrahim supervised the research and provided guidance throughout the article's revision process. Muhammad Yasin Ramadhan Zahari and Dzul Fadli Asraf Dzul-Kifli contributed to the critical review, commentary, and refinement of the manuscript. Abdul Qayyum Zainul, the international industry collaborator, provided key information and insights that informed the data analysis.

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