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Design and Concept Selection of a Modular EV Conversion Kit for Automatic Motorcycles with the *Bahana Nusantara Hijau* Theme for Mobility in Indonesia

Patrisius Edi Prasetyo[1*], M. Fahrudin Al Fadli[2]
[1,2] Prodi Desain Produk,Jurusan Desain, Fakultas Seni Rupa dan Desain, Institut Seni Indonesia Yogyakarta
Jl. Parangtritis Km. 6,5, Glondong, Panggungharjo, Sewon, Bantul, Daerah Istimewa Yogyakarta 55188, Indonesia
Alamat Email: patris@isi.ac.id[*], fahrudinalfadli@gmail.com

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Abstrak

Polusi udara perkotaan, yang terutama disebabkan oleh emisi dari sepeda motor konvensional, tetap menjadi masalah lingkungan dan kesehatan masyarakat yang krusial di Indonesia. Meskipun pemerintah telah memperkenalkan berbagai program insentif, adopsi sepeda motor listrik (EM) secara nasional masih terbatas karena tantangan seperti jangkauan baterai yang kurang memadai, waktu pengisian yang lama, dan investasi awal yang tinggi. Penelitian ini memperkenalkan kit konversi kendaraan listrik (EV) modular yang direkayasa untuk sepeda motor mesin pembakaran dalam (ICEm) yang telah ada, menawarkan sistem propulsi hibrida yang memungkinkan perpindahan mulus antara penggerak listrik dan operasi berbahan bakar. Proses pengembangan menggunakan metodologi pengembangan produk Ulrich dan Eppinger, dengan tahapan sistematis mulai dari pengembangan konsep, pemilihan konsep, hingga pemodelan 3D. Sebanyak 72 alternatif desain dikembangkan melalui pemodelan kotak hitam dan transparan, pencarian solusi internal-eksternal, dan analisis morfologis. Melalui pohon klasifikasi dan teknik multivoting, opsi disaring menjadi 12 konsep dan dievaluasi menggunakan matriks pembobotan. Konsep kode 34 dipilih berdasarkan kriteria seperti kinerja, kemudahan manufaktur, efisiensi biaya, dan ergonomi pengguna. Model 3D akhir, dibuat dengan Autodesk Inventor 2025, mengintegrasikan estetika budaya "Bahana Nusantara Hijau" untuk memperkuat identitas lokal. Kit ini menawarkan solusi praktis dan ekonomis untuk mendorong adopsi EM dan mobilitas berkelanjutan di Indonesia.

Kata kunci: *sepeda motor listrik; konversi EV; kit modular; mobilitas berkelanjutan; desain produk; Indonesia*

Abstract

Urban air pollution, primarily driven by emissions from conventional motorcycles, remains a critical environmental and public health issue in Indonesia. Although the government has introduced various incentive programs, the nationwide adoption of electric motorcycles (EMs) is still limited due to challenges such as inadequate battery range, long charging times, and high initial investment. This research introduces a modular electric vehicle (EV) conversion kit engineered for existing internal combustion engine motorcycles (ICEm), offering a hybrid propulsion system that enables seamless switching between electric drive and fuel-based operation. The development process employs Ulrich and Eppinger's product development methodology, systematically progressing through concept generation, concept selection, and 3D modeling stages. A total of 72 design alternatives were generated using black-box and transparent-box modeling, internal-external searches, and morphological analysis. Through classification trees and multivoting techniques, the options were refined to 12 concepts and evaluated using a weighted scoring matrix. Concept code 34 was selected based on criteria such as performance, manufacturability, cost-effectiveness, and user ergonomics. The final 3D model, created using Autodesk Inventor 2025, integrates a culturally inspired aesthetic—*Bahana Nusantara Hijau*—to reinforce local identity. This modular kit offers a viable, low-barrier solution to accelerate EM adoption and promote sustainable mobility in Indonesia.

Keywords: electric motorcycle; EV conversion; modular kit; sustainable mobility; product design; Indonesia

BACKGROUND

Low public interest remains a major barrier to motorcycle electrification in Indonesia. In 2024, only 63,146 electric motorcycles were sold—about 1% of the 6.3 million internal combustion engine motorcycles (ICEm) registered nationwide (Gilang Satria, 2024; Muhamad Fadli Ramadan, 2025). Electrifying transportation has been widely shown to improve air quality and public health while reducing greenhouse gas emissions Click or tap here to enter text.(Duan et al., 2023; Horton et al., 2021). Two main approaches to motorcycle electrification exist: replacing conventional motorcycles with factory-built electric motorcycles (EMs) or retrofitting ICEm units through electric motorcycle conversion (EMC) (Duan et al., 2023; Jodinesa et al., 2020; Krishna et al., 2022; Mopidevi et al., 2022; Murali Krishna et al., 2023). Despite growing EV adoption in Europe and government subsidies in Indonesia, uptake remains limited due to concerns over battery reliability and high upfront costs (Desiawan, 2022, 2023; ESDM, 2023; Menperin, 2023; Millikin, 2021). Nevertheless, EVs offer distinct benefits: zero tailpipe emissions, superior torque-speed performance, and reduced mechanical maintenance (Amjad et al., 2010; Manzetti & Mariasiu, 2015; Wagner et al., 2013).

This study addresses the need to accelerate motorcycle electrification by reducing user hesitancy during the transition phase. It proposes a modular EV conversion kit for automatic motorcycles, enabling dual-mode operation (electric and gasoline), thereby mitigating range anxiety and preserving the reliability of fuel-based systems. The hybrid solution enhances cost efficiency by reusing existing components such as frame, wheels, and suspension—consistent with typical EMC designs. The design also embraces the "Bahana Nusantara Hijau" theme, symbolizing sustainable innovation through cultural and environmental expression: *Bahana* (resonance), *Nusantara* (archipelago), and *Hijau* (green technology) (Ammar Fahri, 2025; Ayu Rifka Sitoresmi, 2022; Kemdikbud, 2016; Vlekke, 2008). This narrative seeks to foster broader social acceptance of EV technology as an ecologically responsible mobility solution.

Building upon earlier research on user needs and product specification targets (Prasetyo et al., 2023), this study seeks to integrate those inputs into a validated conceptual and 3D design. The core research question is: how can the optimal product concept and detailed 3D model of an EMs conversion kit be developed for automatic motorcycles? The objective is to advance the design through concept generation, evaluation, and selection, following the Ulrich & Eppinger product development framework (Ulrich, Karl T. Eppinger, 2012), resulting in a refined, detail-engineered 3D product model.

Previous studies have examined EV adoption and EMC design. One behavioral study, using the Theory of Planned Behavior and PLS-SEM analysis of 1,602 respondents across 10 provinces, found that attitude, subjective norms, and perceived behavioral control influenced purchase intentions, while moral norms and infrastructure had limited impact. Financial incentives and performance improvements were recommended to support adoption (Agustina et al., 2025). In vehicle retrofitting, another study proposed a dual-mode EV conversion kit for cars featuring a dynamo-based self-charging system linked to the wheels.

The system provided 30 km of electric range after 100 km of conventional driving and automatically stopped charging upon full battery capacity to prevent overcharging (Karunamoorthy & Shobana, 2021).

A previous study successfully converted a three-wheeled Bajaj into a solar-electric vehicle by replacing its combustion engine with a 48V, 1500W BLDC motor, a 48V 100Ah battery, and solar panels, while retaining the original gearbox. Performance tests showed a top speed of 30 km/h, 34 km range (plus 17 km from solar input), 0.106 m/s² acceleration, a 1.26° gradient capability, and 78 seconds to reach 30 km/h (Mohammed et al., 2023). In Colombia, a low-cost hybrid retrofit kit for 125cc motorcycles was developed using the VDI 2206 methodology. The system, controlled via a Finite-State Machine, allowed low-speed and regenerative electric operation, reducing gasoline usage by up to 35% (Polanía-Restrepo et al., 2020). Another comparative study demonstrated that electric motorcycles were 43.3% more time-efficient and 213% cheaper to operate than gasoline variants, with favorable financial indicators (NPV > 0, IRR = 22%, payback = 3.14 years) (Pawenary et al., 2021).

Kawasaki's industry-driven research introduced a 20 kW electric motorcycle prototype (5.2 kWh battery, manual transmission), delivering performance comparable to 250cc gasoline models with 100 km range and 4.2 kWh/100 km consumption. The oil-cooled motor offered 1.9× higher torque. Optimization studies further enhanced energy efficiency by 22.36% using IPOPT and CasADi. Innovations included motor thermal redesigns, adaptive BMS, MATLAB/Simulink-based dynamic simulation, torque sensor-driven traction control, liquid cooling, and regenerative braking optimization (Niccolai et al., 2025). From a design standpoint, Kansei Engineering was applied to align EV aesthetics with user emotion. Through factor analysis and semantic modeling, five design features—angled seat (dynamic), futuristic hood, functional dual-slot luggage, sharp-modern headlamp, and aerodynamic body—were identified and translated into 2D/3D concepts for increased market appeal (Baroroh et al., 2019).

The present study advances the field by developing a plug-in hybrid electric modular conversion kit specifically for automatic motorcycles—an area not previously addressed. As outlined in the research roadmap (Figure 1), the process adopts Ulrich & Eppinger's Front-End Activity model (Ulrich, Karl T. Eppinger, 2012), advancing from user need identification to product concept generation and selection, and culminating in a detailed 3D model to support further development and testing.

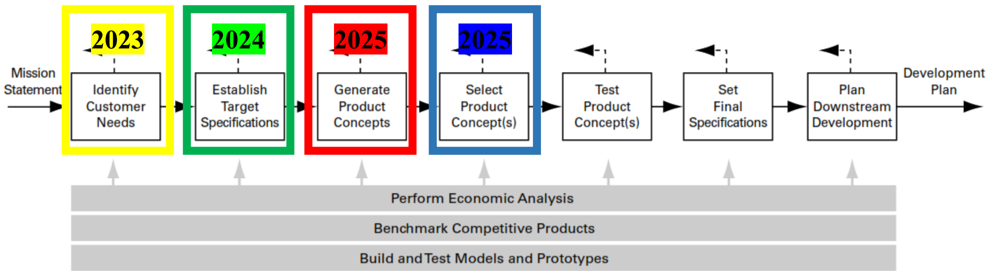


Figure 1. Roadmap of EMs kit module product design activities with front-end activity (Ulrich, Karl T. Eppinger, 2012)

EVs are classified into four main types: Battery Electric Vehicles (BEVs), fully powered by batteries; Hybrid Electric Vehicles (HEVs), combining combustion engines and electric motors; Plug-in Hybrid Electric Vehicles (PHEVs), externally rechargeable; and Fuel Cell Electric Vehicles (FCEVs), which utilize hydrogen fuel cells. These categories provide a conceptual framework for EV and EMC system development (Tiwari et al., 2023). EMs feature a simplified architecture compared to combustion motorcycles, using battery-powered electric motors. Key components include: (1) efficient, low-maintenance BLDC motors (Ehsani et al., 2018); (2) lightweight, durable lithium-ion batteries with high energy density (Linden & Reddy, 2002); (3) controllers that regulate power flow based on throttle input to maintain speed and torque (Chau K. T., 2015); (4) chargers compatible with both standard and fast charging (J. Larminie and J. Lowry, 2012); (5) inverters for DC to AC conversion when necessary; (6) throttle sensors transmitting user input (Husain, 2021); and (7) regenerative braking systems that recover energy during deceleration (Ehsani et al., 2018).

As regulated by Indonesia's Ministry of Transportation, motorcycle electrification requires legally registered vehicles and integration of essential components: battery, BMS, DC–DC converter, motor, controller/inverter, charging inlet, and supporting structures. Batteries must be firmly mounted near the base, shielded from moisture and impact. Motors should minimize vibration and connect directly to the drivetrain. Controllers require proximity to the motor with thermal management, and charging inlets must include interlocks that disable operation during charging (KEMENHUB, 2020).

METHODOLOGY

3.1 Methodological Framework

This research adopts a mixed-method approach, combining qualitative and quantitative techniques to support systematic product development. The study is grounded in the Front-End Activities framework for product design and development as proposed by Ulrich and Eppinger (Ulrich, Karl T. Eppinger, 2012). This method is particularly suitable for early-stage industrial product design where conceptual clarity and iterative decision-making are critical. The research is positioned within the later stages of the front-end process, specifically Activities C to E (see Figure 2), while Activities A and B—user need identification and product specification formulation—were completed in previous work (Prasetyo et al., 2023). This segmentation allows the research to focus on generating, evaluating, and modeling multiple product concepts for a modular electric vehicle (EV) conversion kit designed for automatic motorcycles.

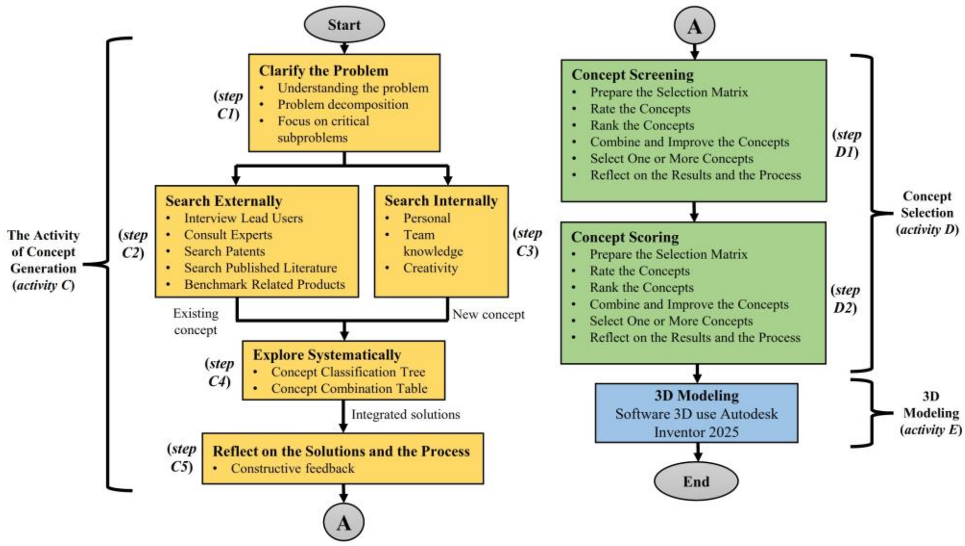


Figure 2. Research Flow Diagram

3.2 Design Procedure

Concept Generation (Activity C), the process begins with functional decomposition (Step C1), where the core function of the conversion kit is analyzed using a "black box" model and then expanded into a "transparent box" model consisting of multiple sub-functions. Interrelations between sub-functions are illustrated using standard notation to represent flows of material (solid lines), energy (thin lines), and signals (dashed lines). In Step C2, external solution searches are conducted via literature review, expert consultation, patent databases, and benchmarking of similar EV products. Simultaneously, Step C3 involves internal solution generation through team brainstorming sessions and previous design insights. Data collection also includes reviewing standard EV components available on online marketplaces. The data-gathering period lasted approximately one week and aimed to obtain the broadest possible range of functional solutions. The collected solution elements are then synthesized in Step C4 into multiple concept alternatives. These combinations are organized based on their compatibility with the transparent box model. To eliminate infeasible or redundant configurations, a classification tree method is used. The result is a refined set of concept alternatives, which are subsequently reviewed in a design team discussion (FGD) to ensure practical alignment with technical and user needs.

Concept Selection (Activity D), step D1 involves concept screening using a decision matrix. Concept alternatives are listed along the top axis, while selection criteria (e.g., user requirements, manufacturability, cost, safety) are arranged on the side. If more than 12 concept alternatives are present, a Multivote technique is applied. A structured questionnaire is distributed to 20 experts in mechanical, electrical, and EV design, who are asked to select 3–5 preferred options. The top 12 concepts with the most votes are retained. Each alternative is compared against a reference product using qualitative assessment: "+" (better), "0" (equivalent), and "–" (worse). Net scores are computed, and high-ranking concepts advance to Step D2, where concept scoring is conducted. In this phase, criteria are weighted based on importance, and each concept is rated on a scale of 1 to 5. Weighted scores are calculated and aggregated to determine the highest-ranking concept.

3D Modeling and Final Integration (Activity E), the top-rated concept is further developed into a detailed 3D CAD model using Autodesk Inventor 2025. The final model integrates both functional and aesthetic elements, including the application of a visual design theme "Bahana Nusantara Hijau". This cultural-ecological theme reflects the product's aim to resonate with local identity while promoting sustainable innovation. The outcome of this research is a validated and fully rendered 3D product model of the EMs modular conversion kit, aligned with prior specifications and optimized for further evaluation and potential prototyping.

RESULTS AND DISCUSSION

User Requirements, Product Metrics, and Conceptual Framework

Based on the preliminary design process, 29 user needs and 24 product metrics were systematically identified to ensure alignment with end-user expectations. These were derived from Activity A (User Needs Identification) and Activity B (Specification Targeting), each metric featuring marginal and ideal values as benchmarks in the EMs kit development. Table 1 (Prasetyo et al., 2023) details these metrics, their importance weights, and target values across key subsystems such as the battery set, electronic control unit, motor assembly, and user interface components. For example, battery-related metrics type, capacity, IP rating, weight, and mounting position are mapped to specific customer needs (CN), with associated units and priority percentages.

The requirement definition is supported by a product concept that articulates key technologies, functions, and physical structure, developed through Activity C (Concept Development) and refined in Activity D (Concept Evaluation). Concept generation began with Step C1 using the black box model, which defines the system through input–process–output relationships. This was elaborated into a transparent box model, detailing subsystems across energy, material, and signal domains. Input includes 220V AC household power and user-generated signals (e.g., throttle twist), while output comprises wheel rotation, battery indicators, and EV mode signals excluding direct material flows.

Table 1. Target Marginal and Ideal Values of EMs Module Conversion Kit Products (Prasetyo et al., 2023)

No Metrics	Kode *Customer Needs* (CN)	Aspect metrics	Metrics	% Important metrics	Unit	Marginal value	Ideal value
1	1, 3, 7, 8, 9, 11, 21, 22, 23, 25, 26, 27,	Battery set	Battery type	9.65%	subj	Lithium-ion	Lithium-ion
2	1, 2, 3, 6, 7, 8, 9, 11, 13, 14, 21, 22		Battery capacity	7.52%	kWh	>1,4	>1,8
3	3, 5, 9, 15, 17, 19, 20, 23, 28, 29		Battery position	5.67%	subj	Outside the motor body, the lowest possible position	Under the seat / inside the motor body
4	3, 4, 5, 15, 17, 20, 23, 24, 25, 28, 29		Battery holder and cover	5.36%	subj	Mounts and covers made of thick plastic must be closed and have seals	The Holder Metal plate plastic/rubber cover must be closed and have a seal.
5	11, 17, 20, 21, 25, 26		Battery IP rating	5.26%	IP	>IP54	>IP67
6	1, 2, 3, 6, 7, 8, 9, 10		Battery voltage	3.80%	Volt	60-72	72 - 73,8
7	3, 5, 15, 21, 24, 28		Battery dimensions	3.25%	mm	<= 140 x <=180 x <=420	<120 x <160 x <400
8	5, 21, 24, 28, 30		Battery weight	2.62%	gram	8.000 – 13.000	<9.000
9	4, 5, 20, 23, 28, 29		Battery lock	1.17%	subj	Plastic/string/rubber latch	Metal latch
10	1, 2, 3, 4, 5, 20, 21, 22, 25, 26, 27,	Electronic component set	Charging device	6.46%	Volt, Ampere, Watt	Voltage and current to match battery, power <= 300 W	Voltage & current adjust to battery, standard charging <=200W & fast <=500W
11	6, 7, 11, 12, 13, 14, 17, 19, 21, 27, 28, 29		Display panel	4.26%	subj	Built-in ICEm, additional LED / 7 segment light indicator, integrated with ICEm indicator panel	Built-in ICEm, additional MID display, integrated with ICEm indicator panel.
12	6, 12, 17, 19, 29		Control panel	2.36%	subj	ICEm standard panel + additional integrated right/left panel part of ICEm	Standard ICEm + additional panel integrated into the right panel of ICEm, EMs panel buttons have special features.
13	14, 19, 21, 27, 28		Notification sound	1.59%	subj	Notification of battery less than 50% when not in use	Notification of battery less than 50% when not in use, alarm, electric motor on-off system

Table 1. Target Marginal and Ideal Values of EMs Module Conversion Kit Products (Prasetyo et al., 2023) (Continued)

No Metrics	Kode *Customer Needs* (CN)	Aspect metrics	Metrics	% Important metrics	Unit	Marginal value	Ideal value
14	1, 3, 19, 20,		MCB	1.50%	Ampere	Customize depending final specification	Customize depending final specification
15	7, 8, 9, 10, 20, 21, 22,	Electric motor set	Electric motor power	4.85%	Watt	1.200 – 1.800	1.500 – Peak Power 3.000
16	10, 23, 25, 26, 27,		Type of electric motor	4.34%	subj	BLDC mid-drive/hub-drive	BLDC mid-drive
17	15, 20, 24, 29		Electric motor position	3.35%	subj	Mid-Drive/hub-drive, attaches to ICEm frame/engine/swing arm/wheels	Mid-drive, attached to the main frame
18	15, 20, 24, 26, 27, 28, 29		Electric motor adapter	2.76%	subj	Metal adapter, attached to swing arm/engine	Metal adapter, attached to the main frame
19	11, 17, 20		IP Rating of the Electric Motor	2.66%	IP	IP54	IP67
20	2, 11, 22, 30		Self-charging electric motor	2.30%	Ampere	>3A	4 – 6A
21	7, 8, 9, 10		Electric motor voltage	2.26%	Volt	60 - 72	72
22	15, 17		Electric motor cover	1.62%	subj	Full coverage of electric motors	Comprehensively covers the electric motor with seals to protect against dust and water.
23	1, 2, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 19, 20, 21, 22, 24, 25, 26, 27	Controller set	Controller	13.47%	volt, Ampere	60 – 72 V, 0,8 – 2 kW	48-72, 0,8 - 3kW
24	16, 20, 23	Marker	Identification stickers	1.89%	subj	Following the Standard of PERMENHUB RI NO PM 65 TAHUN 2020	Following the Standard of PERMENHUB RI NO PM 65 TAHUN 2020

Figure 3 illustrates the system's transition from a black box (abstract system-level view) to a transparent box (detailed subsystem mapping). The black box defines the core operational principle: transforming inputs into outputs. The transparent box expands on this by mapping subsystems and their interconnections. Thin, thick, and dashed arrows denote energy, material, and signal flows, clarifying each subsystem's functional role. The system receives 220V AC, converted by the charger into DC for the lithium battery. The battery powers the controller, which drives the BLDC motor to rotate the motorcycle wheel via an adapter or transmission. The controller processes input signals from the on/off switch and throttle sensor, and sends output to the indicator panel showing battery status and EV mode.

Additionally, during deceleration or fuel-engine operation, reverse torque from the motor enables regenerative braking, converting kinetic energy into electricity for battery recharge. Functionally, the EMs kit comprises seven interconnected subsystems: Switch on/off, Throttle sensor, Lithium battery with charger, Controller, BLDC motor, Adapter/Transmission, and Indicator panel. Following this model in Step C1, Steps C2

(External Search) and C3 (Internal Search) identify and select design alternatives for each subsystem, supporting further system integration.

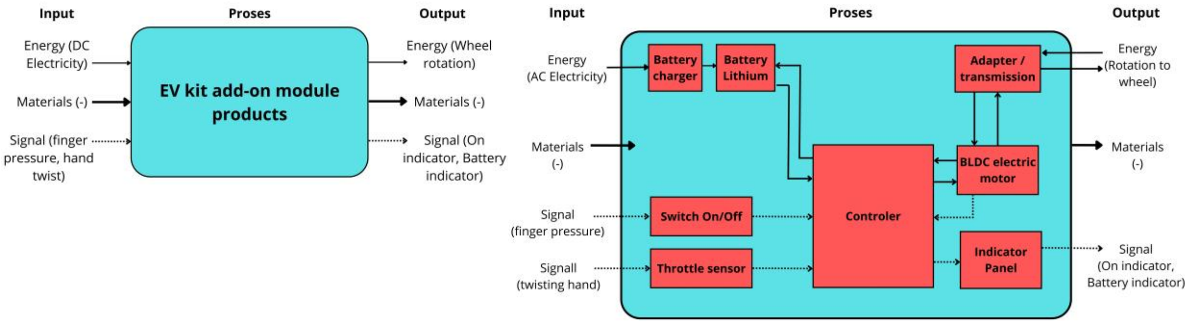


Figure 3. Black box dan transparant box model

Concept Generation and Subsystem Configuration Analysis (C2, C3, and C4 Activities)

Concept generation (C2) was conducted using external sources such as user feedback, expert insights, patent databases, literature, and benchmark products. This was complemented by internal ideation (C3) through individual inputs and FGDs within the design team. Additional component-level alternatives were explored via online marketplaces and official manufacturer websites relevant to the EMs kit. The combined C2 and C3 activities produced multiple design alternatives for each subsystem (Table 2): seven for the switch on/off, three for the throttle sensor, eight for the lithium battery, six for the controller, four for the BLDC motor, four for the adapter/transmission, and five for the indicator panel. These alternatives formed the basis for C4 activity, where options were assessed for integrative compatibility and technical feasibility.

Table 2. Comprehensive Listing of The Proposed Subsystem Alternatives Derived from C2 and C3

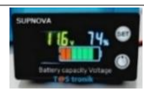
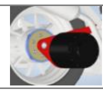
No	Switch on/off (A)	Throttle sensor (B)	Battery Lithium (C)	Controler (D)	BLDC electric motor (E)	Adapter / Transmission (F)	Indicator Panel (G)
(1)	 single press switch, light on, attached to the body (punches the body)	 Separate throttle sensor, BRT brand, metal material	 "CNS" brand battery 72V DC 55 Ah (3.96 Kwh), dimensions 355 x 210 x160 mm	 Votol EM 100 Programmable 72V 80A 80KPH Controller for 2-3kW, dimensions 218x124x62mm	 BLDC mid drive BRT brand (QS 120 Motor QSD120A-70), 72V 2 Kw 4400 rpm, dimensions 211x130x130 mm	 Adapter for mid drive motor + timing belt transmission ratio 1:3	 Battery Capacity Indicator Voltmeter Voltage Tester 9-100V, Operating current: <5mA, Display mode: LCD percentage% / voltage, Color: White, Waterproof grade: surface waterproof, dimensions 61.3x33.3x13.5 mm
(2)	 single push switch, no light, attached to handle bars	 Throttle sensor integrated with gas grip, plastic material	 "CNS" battery 72V DC 30 Ah (2.16 Kwh), dimensions 270x160x180 mm	 Votol EM-150, 48-72V (max.90V), Battery Current: 150A (peak), power: 3-4KW, dim 245x129x69mm	 BLDC mid drive QS Motor (QS 2500W QSD138A-60), 72V 2.5 Kw 3000 rpm, dim 197.8x140x140mm	 Adapter for mid drive motor + transmission gear ratio 1:3	 Supnova Battery Capacity Indicator Lead Acid Battery LY6W. Voltage measurement range:DC8-80V, Measurement accuracy: 1% ±1, Refresh rate: 2x per second, Dim: 60x33x15 mm
(3)	 single push switch, light on, attached to the handle bars	 Separate throttle sensor, plastic material	 "Gesit" Battery 72V DC 20 Ah (1.44 Kwh), dimensions 410x119x127 mm	 BRT Juken 10 Controller EV, BLDC 0.8-3Kw Voltage 48-72v-Self CL-Waterproff-Programmable.	 Motors for Electric Vehicle QS205 V3 3000W, 48 - 96 V DC, (72V default), efficiency: 85~92%, dim. 340×340×350mm	 Adapter for hub motor, without transmission	 LCD Battery Indicator (battery indicator bar & percentage) 12V-72V 3S-28S Waterproof Lithium ION LiFePO4 BATTERY, dimensions 61.3x33.3x13.5mm
(4)	 separate push switch, lights up, attached to the rearview mirror		 "BRT" Brand Battery 72V DC 20 Ah (1.44 Kwh), dimensions 392x 118x127mm	 48V 60V 64V 72V 84V 3000W Electric Motor Sine Controller, Sine Wave	 QS 2500W 50Nm QSJ138F-55 72V 55H 4700RPM Max 120A gear ratio 1:2.35 Encoder Mid Drive Motor, Dimension: 340x 340x360mm	 Adapter for mid drive motor + Sprocket transmission ratio 1:3	 h56c lcd digital meter battery capacity 200A 0-100v, support (-/LiFePo4/Lead-acid) battery, voltage range (12V/24V/36/72V/80V) display battery capacity, current, charge and discharge time, battery percentage, battery power, dimension 79x43x27mm.

Table 2. Comprehensive Listing of The Proposed Subsystem Alternatives Derived from C2 and C3 (Continued)

No	Switch on/off (A)	Throttle sensor (B)	Battery Lithium (C)	Controler (D)	BLDC electric motor (E)	Adapter / Transmission (F)	Indicator Panel (G)
(5)	 separate push switch, no lights, attached to the rearview mirror		 PHYLION by HINERGI Battery, 72V 24 Ah (1,728Kwh), 184x165x300 mm	 Universal BLDC controller EM-100 48/60/72v 3000W, 80A, dimensions 225x110x50 mm			 Battery Indicator 5918, Voltage range: 8-100V, Waterproof , Working current: ≤15MA, Temperature detection: -20~80 °,casing dia: 55mm, screen dia: 43mm
(6)	 separate push switch, no lights, attached to handlebars		 LiTech Battery, 72V 37.8 Ah (2.72 Kwh), dimensions 160x140x408 mm	 SIAECOSYS ND72300 Controller 72V C 100A, Protect 300A BLDC Programmable, 3KW			
(7)	 separate push switch, no lights on, replaces the right switch on the motorcycle		 Bonnem Brand Battery, 72V 30 Ah (2.16 Kwh), dimensions 178x172x290 mm				
(8)			 Bonnem Battery, 72V 40 Ah (2.88 Kwh), dimensions 200x200x27 mm				

Systematic Exploration through Classification Tree Analysis (C4)

Activity C4 systematically evaluated subsystem alternatives using classification trees, which organized each option hierarchically by its technical attributes. This structure enabled targeted analysis and the elimination of redundant, unfeasible, or underperforming alternatives. The refined selection is summarized in Table 3, with subsystem codes as follows: (A) switch on/off, (B) throttle sensor, (C) lithium battery, (D) controller, (E) BLDC motor, (F) adapter/transmission, and (G) indicator panel. Based on this selection, 72 system-level configurations were generated by combining the alternatives mathematically: 1(A)×2(B)×3(C)×1(D)×2(E)×3(F)×2(G), as detailed in Table 4 (APPENDIX).

Table 3. Classification Tree Analysis Results for EMs Conversion Kit Subsystems

Switch on/off	Throttle sensor	Battery Lithium	Controler	BLDC electric motor	Adapter / Transmission	Indicator Panel
(A)	(B)	(C)	(D)	(E)	(F)	(G)
A4	B1	C3	D3	E2	F1	G3
	B3	C6		E3	F3	G5
		C7			F4	

Feasibility Refinement and Final System Selection

All 72 system configurations underwent technical feasibility screening. A critical constraint was found in the E3 subsystem (hub-type BLDC motor), which requires direct pairing with F3 (direct drive adapter) due to its integrated housing. Configurations combining E3 with incompatible adapters (F1 or F4) were thus excluded. These infeasible combinations are marked in red in Table 4 (APPENDIX). After applying these constraints, 36 viable system alternatives remained, as finalized in Table 5 (APPENDIX 1). Following Activities C1–C4, Activity C5 reviewed the design outcomes. Table 4 lists all 72 feasible subsystem combinations, each denoted by a code and comprising alternatives for: (A) Switch on/off, (B) Throttle Sensor, (C) Lithium Battery, (D) Controller, (E) BLDC Motor, (F) Adapter/Transmission, and (G) Indicator Panel—derived from prior classification tree analysis. Two key insights emerged: (1) 36 remaining viable combinations still posed selection challenges, and (2) lithium battery options (C3, C6, C7) differed significantly in size, capacity, and cost, warranting further evaluation.

To streamline selection in Activity D (Concept Selection), a preliminary filtering was conducted via multivote. A panel of 20 electronics and EV experts each nominated 3–5 promising system alternatives. Votes were tallied and ranked, yielding 12 top alternatives (codes: 2, 9, 10, 13, 14, 21, 22, 33, 34, 42, 45, 46) for screening in D1. These represent the most balanced configurations in terms of technical and user criteria. Table 5 (APPENDIX 2) summarizes the vote distribution and Table 6 (APPENDIX 3) presents the specific subsystem combinations that define each alternative concept.

Concept Screening in EMs Kit Product Development

The concept screening phase began with the creation of a selection matrix, listing the design criteria (based on Front-End Activity frameworks) in the left column and the system/concept alternatives—alongside a reference concept—across the top. The reference was a commercial electric conversion kit by BRT for the Honda Beat, equipped with a 72V 20Ah lithium battery (1.44 kWh), a 2000W BLDC motor, and a Juken 10 controller. Its conversion involves engine removal and adaptation of existing mechanical parts to fit the electric drivetrain. Each alternative was scored relative to the reference using a qualitative scale: better (+1), same (0), or worse (−1). The total score was derived by summing all criteria scores. Four alternatives (codes 21, 22, 33, 34) shared the highest score (+2), while two others (codes 9 and 10) followed with +1. Based on rankings, six alternatives codes 9, 10, 21, 22, 33, and 34 were selected for the concept scoring phase (D2). Full results are shown in Table 7.

Table 7. Selection Matrix for Concept Screening in the EMs Kit Product Design Process

Selection Criteria	**Alternative Sistem/Concept (combination code)**												
	BRT Convertion (Honda Beat)	2	9	10	13	14	21	22	33	34	42	45	46
Cost	0	0	0	0	-	-	-	-	-	-	0	0	0
Performance	0	+	+	+	+	+	+	+	+	+	+	+	+
Range	0	-	-	-	+	+	+	+	+	+	-	-	-
Manufacturability	0	+	+	+	+	+	+	+	+	+	+	+	+
User Comfort	0	-	0	0	-	-	0	0	0	0	-	0	0
Durability	0	0	0	0	0	0	0	0	0	0	-	-	-
Compactness	0	-	0	0	-	-	0	0	0	0	-	0	0
Total (+)	0	2	2	2	3	3	3	3	3	3	2	2	2
Total (0)	5	2	4	4	1	1	3	3	3	3	1	2	2
Total (-)	0	3	1	1	3	3	1	1	1	1	4	2	2
Final Score	0	-1	1	1	0	0	2	2	2	2	-2	0	0
Ranking	3	4	2	2	3	3	1	1	1	1	5	3	3
Selected for Next Phase?	no	no	yes	yes	no	no	yes	yes	yes	yes	no	no	no

Concept Scoring and Design Reflection in EMs Kit Product Development

Following the completion of the concept screening stage (D1), the process proceeded with a critical reflection on both outcomes and methodology. The design team identified that six system alternatives might be overly broad, prompting the need for a more structured decomposition of selection criteria and improved weighting in the next phase. It was also concluded that no further combinations were feasible, as each concept already embodied the most comprehensive subsystem integrations.

In the concept scoring phase (D2), these six shortlisted concepts were evaluated using a refined selection matrix. Criteria were decomposed into sub-criteria with specific weight percentages reflecting their importance. Table 8 presents the matrix, listing sub-criteria weights vertically and the six concept alternatives (codes 9, 10, 21, 22, 33, 34) horizontally. Each was rated on a 5-point scale relative to a reference, then multiplied by the sub-criterion weight to yield weighted scores. Total scores determined the final ranking. Combination code 34 attained the highest score (4.08), reflecting superior performance in cost efficiency, top speed, acceleration, ease of assembly, and water resistance. Full scoring results are shown in Table 8, while technical specifications for the selected concept are detailed in Table 9. A design reflection highlighted that the top three concepts (codes 22, 33, and 34) had marginal score differences, indicating close competitiveness. Thus, concepts 22 and 33 will be retained as backup options should implementation issues arise with concept 34.

Table 8. Concept Scoring Selection Matrix (Design Step D2) of the EMs Kit Module

Selection Criteria	**Sub Selection Criteria**	**Weight / criteria (%)**	**Weight / sub criteria (%)**	**Alternative Sistem/Concept (combination code)**											
				9		10		21		22		33		34	
				Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Cost	Standard Component Cost	20	10	3	0.3	3	0.3	2	0.2	2	0.2	3	0.3	3	0.3
	Material Cost		3	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15
	Transmission Cost		3	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15
	Machining and Assembly Cost		4	5	0.2	5	0.2	5	0.2	5	0.2	5	0.2	5	0.2
Perfor-mance	Maximum Speed	15	9	4	0.36	4	0.36	5	0.45	5	0.45	5	0.45	5	0.45
	Acceleration		6	4	0.24	4	0.24	5	0.3	5	0.3	5	0.3	5	0.3
Range	Maximum Travel Distance	15	15	2	0.3	2	0.3	5	0.75	5	0.75	4	0.6	4	0.6
Manufac-turability	Ease of Component Fabrication	15	6	4	0.24	4	0.24	4	0.24	4	0.24	4	0.24	4	0.24
	Ease of Assembly		9	5	0.45	5	0.45	5	0.45	5	0.45	5	0.45	5	0.45
User Comfort	Handling	15	8	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
	Weight Distribution		7	2	0.1	2	0.1	2	0.1	2	0.1	3	0.15	3	0.15

Table 8. Concept Scoring Selection Matrix (Design Step D2) of the EMs Kit Module (Continued)

Selection Criteria	**Sub Selection Criteria**	**Weight / criteria (%)**	**Weight / sub criteria (%)**	**Alternative Sistem/Concept (combination code)**											
				9		10		21		22		33		34	
				Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Durability	Water Resistance	15	6	3	0.12	4	0.16	3	0.12	4	0.16	3	0.12	4	0.16
	Shock Resistance		6	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
	Dust Resistance		3	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
Compact-ness	Dimensional Add-on	10	5	3	0.09	3	0.09	3	0.09	3	0.09	3	0.09	3	0.09
	Installation Neatness		5	2	0.1	2	0.1	2	0.1	2	0.1	3	0.15	3	0.15
Total Weighted Score				3.49		3.53		3.99		4.03		4.04		4.08	
Final Ranking				6		5		4		3		2		1	
Decision				No		No		No		No		No		Develop	

Table 9. Selected System Concept Specification for the EMs Kit Additional Module

Combination code	**Switch on/off**	**Throttle sensor**	**Battery Lithium**	**Controler**	**BLDC electric motor**	**Adapter/ Transmission**	**Indicator Panel**
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
34	 A4 separate push switch, lights up, attached to the rearview mirror	 B1 Separate throttle sensor, BRT brand, metal material	 C7 Bonnem Brand Battery, 72V 30 Ah (2.16 Kwh), dimensions 178x172x2 90 mm	 D3 BRT Juken 10 Ecu Controller EV, BLDC 0.8-3Kw Voltage 48-72v-Self Learning Calibration-Waterproff-Programmable	 E3 Motors for Electric Vehicle QS205 V3 3000W, 48 - 96 V DC, will be 72 V as default, efficiency: 85~92%, dimensions 340×340×350 `mm	 F3 Adapter for hub motor, without transmission	 G5 Battery Indicator 5918, Voltage range: DC8-100V, Waterproof , Working current: ≤15MA, Temperature detection: -20~80°,casing dia: 55mm, screen dia: 43mm

3D Product Modeling and Visual Identity Implementation

The next phase in the product development process (Activity E) focused on generating a three-dimensional (3D) model of the additional EMs kit module. This model was developed based on prior design outputs, including the targeted product specifications (Table 1) and the selected system concept (Table 9). A conventional scooter-type motorcycle was used as a reference to simulate integration; the Honda Ruckus (Zoomer) was selected as the base model. Figure 4 illustrates the installation scenario, with the left image showing the original configuration and the right showing the post-installation condition. The module's integration increased the dimension on the lower left swingarm side by approximately 53mm.

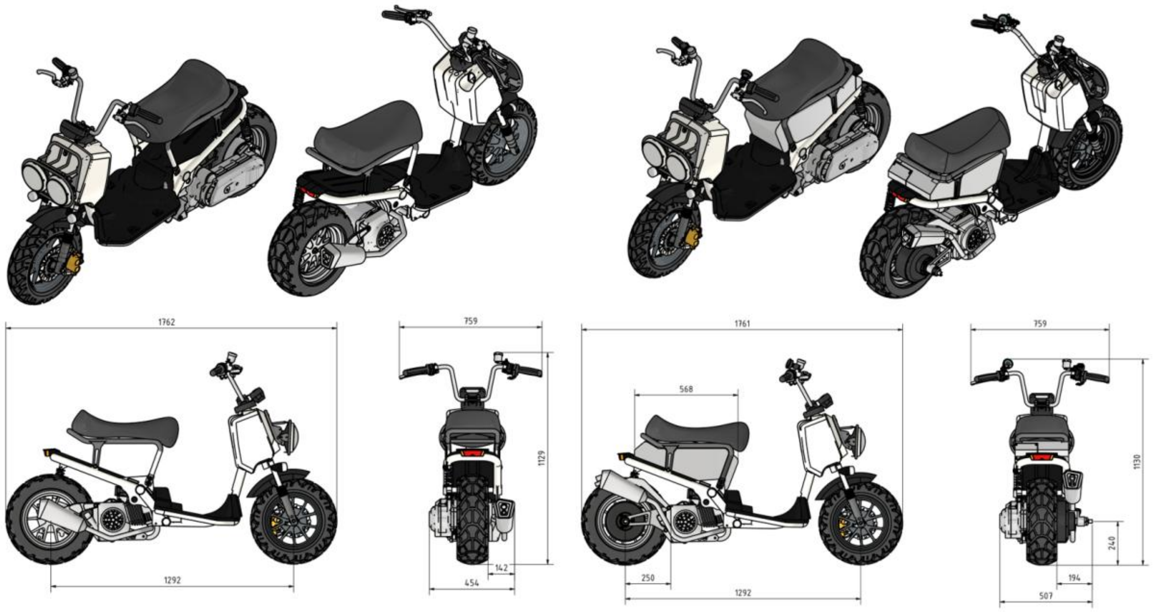
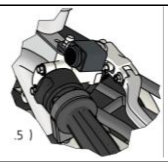
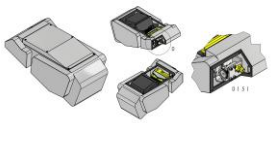
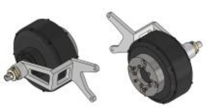


Figure 4. Installation of the Additional EMs Kit Module on a Scooter-Type Motorcycle

The 3D model was structured as a modular system comprising four key components: (1) Switch On/Off, (2) Main Box, (3) Motor and Adaptor, and (4) Indicator Panel. Each component is affixed to designated points on the motorcycle. Functional roles and component breakdowns are detailed in Table 10.

Table 10. 3D Model Description of the EMs Kit Module Components

Component	Description
1. Switch on/off 	Installed on the right handlebar, this switch activates or deactivates the battery-powered electric motor mode. When engaged, an indicator light illuminates. The internal combustion engine must remain off during electric operation, although the ignition key stays in the "on" position.
2. Main box 	Houses the lithium battery, controller, and throttle sensor in a compact enclosure. Access is provided from the top (battery and controller) and rear (throttle sensor), with rubber gaskets ensuring dust and water resistance. The battery is bottom-mounted and cushioned on all sides for stability and impact protection.
3. Motor and adaptor 	The BLDC motor and its aluminum adaptor drive the rear wheel. The adaptor is mounted to the right engine crankcase via the existing exhaust bracket bolts. Rear wheel modifications are required to accommodate the adaptor's bolt interface.
4. Indicator Panel 	Displays system status and operational mode. Positioned within the rider's field of vision, it provides visual feedback during electric motor engagement and alerts the user to battery or system issues.

Application of *Bahana Nusantara Hijau* Visual Theme

Following the 3D modeling, the aesthetic identity of the EMs kit module was further developed through the application of a culturally inspired decal theme, titled *Bahana Nusantara Hijau*. The decal is applied to both the battery cover and the motor adaptor surfaces, as depicted in Figure 5.

Figure 5. *Bahana Nusantara Hijau* Decal Theme Visualization

The *Bahana Nusantara Hijau* theme was conceptualized as a visual communication strategy that aligns with sustainability principles and cultural identity. The predominant use of deep green symbolizes ecological values such as natural balance, energy efficiency, and a shift towards low-carbon transportation ecosystems (Titisari, 2023), (Utami, 2024). This visual approach embodies the principles of eco-design, wherein aesthetics and functionality are harmonized to express environmental values symbolically.

Figure 6. Final Application of The *Bahana Nusantara Hijau* Decal on The EMs Kit Module

The decorative patterns incorporate symmetrical and repetitive geometric elements inspired by traditional *Nusantara* motifs, producing a harmonious visual rhythm that bridges heritage and technological modernity (Cahyaningrum, 2024). In the context of sustainable design, such cultural integration serves as a key strategy to foster emotional and social attachment between users and technological products (Legino et al., 2024). The absence of verbal or brand-specific symbols ensures inclusivity and neutrality, allowing the message of sustainability to be conveyed universally. As a surface graphic, this decal not only enhances the visual appeal of the vehicle but also functions as a non-verbal medium for promoting the transition towards future-oriented, sustainable mobility (Titisari, 2023). The final implementation of the decal design on both the battery cover and the electric motor adaptor, when mounted onto the scooter-type motorcycle, is comprehensively illustrated in Figure 6, demonstrating the cohesive integration of the aesthetic theme with the product's physical form.

CLOSING

Conclusion

The design process of the additional EMs kit module has been successfully finalized, resulting in the selection of the optimal system/concept (Table 9) and the development of detailed 3D models for all components (Table 10), integrated into a scooter-type motorcycle (Figure 4). This modeling phase was informed by Activities C and D, which produced the working concept and defined target specifications, both ideal and marginal (Table 1). Additionally, the design incorporates a visual identity—*Bahana Nusantara Hijau*—applied as decals on the battery cover and motor adaptor, visually enhancing the final installation. Nevertheless, practical deployment on various motorcycle types may necessitate adjustments, particularly to sub-systems like the Lithium Battery, BLDC Motor, and Adapter/Transmission, to accommodate different spatial and structural constraints. For instance, in compact scooters such as the Honda Beat, a large battery may be impractical, requiring alternative configurations to maintain functionality.

Suggestion

Future work should focus on refining the 3D model and constructing physical prototypes for empirical validation. This will enable iterative improvements based on real-world testing, aligning the product more closely with user requirements and supporting the broader adoption of electric motorcycles in Indonesia.

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