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Understanding Pro-Environmental Behaviour in Smart City Tourism: The Interplay of Sustainability, Technology Readiness, and Place Engagement in Kuala Lumpur

Liyuan Wang, Ahmad Azmi Mohd Ariffin*

UKM-Graduate School of Business, Universiti Kebangsaan Malaysia, UKM Bangi 43600, Malaysia

Corresponding Author Email: aama@ukm.edu.my

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ABSTRACT

Smart city tourism is increasingly promoted as a pathway to more sustainable urban travel, yet the mechanisms that translate smart and sustainable destination initiatives into tourists' actual pro-environmental behaviour (PEB) remain under-explained, particularly in Southeast Asian capital cities. This manuscript investigates how perceived sustainability of smart city tourism (PSS) shapes PEB through tourists' place engagement (PENG), and whether technology readiness (TR) strengthens or weakens these relationships in Kuala Lumpur. This study employed a cross-sectional quantitative design. A structured questionnaire using 5-point Likert items measured PSS, PENG, TR, and tourist PEB among tourists in Kuala Lumpur. Data from 420 valid responses were analysed using partial least squares structural equation modelling with bootstrapping of 3,000 resamples. PSS positively influenced PEB ($\beta = 0.318$, $p < 0.001$) and PENG ($\beta = 0.403$, $p < 0.001$). PENG positively influenced PEB ($\beta = 0.422$, $p < 0.001$) and partially mediated the effect of PSS on PEB (indirect $\beta = 0.170$, $p < 0.001$). The PSS × TR interaction was positive and significant ($\beta = 0.160$, $p < 0.001$), indicating that the sustainability–behaviour link is stronger for more technology-ready tourists. The model explained 44.4% of the variance in PEB ($R^2 = 0.444$). The study integrates sustainable smart city tourism with psychological PENG and TR to explain tourist PEB in Kuala Lumpur. Practically, it suggests that sustainability interventions in smart cities should combine visible sustainability cues with technology-enabled choice architecture (e.g., eco-route planning, real-time public transport information, and digital nudges) to convert engagement into action.

1. INTRODUCTION

Urban tourism is being reshaped by two parallel transitions: the sustainability and digital transitions. On the one hand, cities face accelerating environmental pressures (energy use, waste, air quality, urban heat, mobility emissions) that intensify during peak visitor periods and are concentrated in iconic districts. On the other hand, tourists increasingly navigate, consume, and co-create experiences through smart infrastructures and services such as location-based information, mobility platforms, cashless payment systems, e-tickets, real-time crowding dashboards, and digital wayfinding. The convergence of these transitions is often labelled smart city tourism or smart tourism destinations, in which technology is expected to increase efficiency while supporting sustainability outcomes [1-3].

Kuala Lumpur cannot be considered as a generic smart tourism location but instead, as a concrete case of urban sustainability. The Smart City Master Plan 2021-2025 by Dewan Bandaraya Kuala Lumpur places tourism experience under the umbrella of technology, smart mobility, smart environment, smart waste management, and smart traffic management, along with the issues of traffic congestion, interconnected transport, first and last mile accessibility, carbon footprint, and recycling awareness as ongoing challenges [4]. Meanwhile, the Kuala Lumpur Traffic Master Plan 2040 aims at a 70:30 modal split between public transport and private vehicles and highlights active mobility and supporting first mile and last mile access as the precondition of the changing travel behaviour [5].

As a behavioural problem, these conditions pose a practical problem to tourists commuting between high-demand precincts like the KLCC district, Bukit Bintang, Central Market and heritage districts. There might be lower-impact solutions, but these variants are competing with time constraints, incomplete information in the city, and routines based on convenience. The current research streams do not explain this problem as a whole. Smart tourism literature has been keen on adoption, satisfaction, and revisit results whereas pro-environmental behaviour (PEB) literature has been keen on the values, norms as well as attitudes without analyzing the influence of digitally mediated urban infrastructure in determining behavioural opportunity structures within the urban environment. The current research thus starts with a problem context in Kuala Lumpur and poses a question of how perceived sustainability of smart city tourism (PSS), place engagement (PENG) and technology readiness (TR) combine to influence PEB of tourists in this metropolis.

Tourist PEB in cities includes actions such as using public transport or walking instead of private vehicles, reducing littering, sorting waste, respecting green spaces, and complying with local environmental practices during the visit [6-8]. While these behaviours are often studied in nature-based and rural destinations, the urban tourism context is distinct because behavioural options are strongly shaped by infrastructure, information architectures, and service design. Smart city tourism, in principle, can make sustainable choices easier through real-time information, choice architecture, and low-friction access to public transport [9, 10]. Yet, tourists differ substantially in their willingness to act and in their capability to use technology to support action.

Three constructs are increasingly highlighted as key to understanding sustainable behaviour in smart destinations: PSS of the destination offer, tourists' TR, and their engagement with the place. First, PSS captures tourists' assessments that a destination's smart services, infrastructure, and governance support environmental and social well-being. When sustainability cues are visible and credible, tourists may interpret them as signals that PEB is valued and normative in the setting [11]. Second, TR reflects a person's propensity to embrace new technologies and feel confident using them for travel decisions. TR shapes whether tourists can leverage smart tools (apps, QR systems, digital ticketing, trip planners) that reduce the 'effort cost' of sustainable choices [12, 13]. Third, PENG refers to the cognitive, emotional, and behavioural connection tourists develop with the destination. Engagement and attachment have been shown to predict stewardship and environmentally responsible behaviour because tourists feel a sense of care and responsibility toward the place [14-16].

Existing research streams often treat these drivers separately: smart tourism studies emphasise satisfaction and behavioural intentions related to technology (e.g., use intention, revisit, recommendation), while sustainable tourism studies emphasise values, norms, and attitudes toward responsible behaviour. Bridging these streams is increasingly recommended, because technology is not merely a service channel; it is also a behavioural infrastructure that can shape what tourists notice, value, and do [2, 10, 11]. In parallel, engagement-based perspectives suggest that sustainability interventions may be more effective when tourists feel psychologically connected to the destination and see themselves as part of its story, rather than as transient consumers [14, 15].

Accordingly, the present study proposes and tests a model in which PSS influences tourist PEB directly and indirectly via PENG, while TR strengthens the conversion of sustainability perceptions into behavioural action. This approach aligns with contemporary stimulus–organism–response logic, frequently used to explain sustainable consumer behaviour in tourism settings, in which destination cues (stimuli) influence internal states such as engagement (organism), which in turn lead to behaviour (response) [15]. It also resonates with digital sustainability research suggesting that technology enables sustainability when it reduces friction, provides feedback, and reinforces social norms for action [10, 13].

The contribution of this study lies not in introducing entirely new constructs, but in specifying their interplay in a concrete urban smart tourism problem. First, the study shifts attention from smart tourism as a technology adoption issue to smart tourism as a behavioural sustainability issue, namely whether tourists in a dense metropolitan destination convert destination-level sustainability cues into everyday low impact action. Second, it positions PENG as an action-proximal mechanism that is more suitable than a purely enduring bond construct for explaining behaviour during a short urban visit. Third, it conceptualises TR as a dual digital capability mechanism that operates both directly and conditionally, clarifying why the same smart sustainability environment can produce different behavioural outcomes across tourists. Kuala Lumpur is therefore not treated as a convenient application site, but as a theoretically relevant context in which digital infrastructure, urban mobility frictions, and place-based meanings intersect.

1.1 Perceived sustainability of smart city tourism of smart city tourism

PSS refers to tourists' evaluations of whether the destination's tourism system—its infrastructure, services, governance, and visitor management- supports environmental protection, socio-cultural integrity, and long-term urban well-being. In smart city tourism, sustainability cues may be embedded in both physical systems (walkable districts, rail connectivity, recycling facilities, green public spaces) and digital layers (e.g., apps that recommend eco-routes, congestion information, digital tickets that reduce paper use, real-time air-quality dashboards, and digital interpretation that replaces printed brochures). Recent research emphasises that smart destinations should not define 'smartness' purely as technological sophistication, but as a socio-technical capability that improves quality of life and sustainability outcomes [1, 3, 9].

From a behavioural perspective, PSS is a 'destination-level stimulus' that can shape what tourists believe is expected, feasible, and valued in the setting. When tourists perceive that a city invests in sustainable systems, they infer that pro-environmental conduct is socially supported and institutionally facilitated. Studies using norm-based frameworks highlight that sustainability initiatives can activate personal responsibility and a moral obligation to act, especially when tourists view destination actors (institutions, businesses, communities) as credible stewards [6, 11]. Similarly, value–belief–norm approaches suggest that sustainability cues influence PEB through eco-destination image and environmental knowledge, and that these influences can be strengthened by personal values [17].

In smart city contexts, sustainability cues may operate through digital choice architecture. Digitalisation can reduce the transaction costs of sustainable behaviour by making eco-options visible and convenient (e.g., showing the fastest low-carbon route, indicating live public transport arrivals, or highlighting nearby water refill points). Digitalisation can also provide feedback loops (e.g., carbon footprint estimates, rewards for green mobility) and facilitate social coordination (e.g., shared mobility platforms). Empirical studies increasingly report that tourists' perceptions of digitalisation and smart development can strengthen perceptions of sustainability and foster environmentally sustainable lifestyles and behaviours [10, 13].

However, sustainability perceptions do not always translate into action due to the well-documented attitude, behaviour gap. In urban tourism, the gap can be widened by time pressure, convenience seeking, unfamiliarity with local systems, and the cognitive load of navigating complex cities. This highlights the importance of identifying psychological

mechanisms that connect sustainability perceptions to behaviour [2, 15]. In this manuscript, PENG is proposed as such a mechanism: PSS can make visitors feel that the city is worth caring about, thereby strengthening their engagement and stewardship orientation [14, 16].

The positive effect of smart sustainability cues should not be treated as automatic. Tourists often behave less pro-environmentally during travel than in everyday life because time pressure, novelty seeking, and convenience priorities can override prior environmental habits [7]. In smart tourism settings, further frictions may arise when digital systems create information overload, undermine digital well-being, or trigger privacy and security concerns that reduce willingness to use data-intensive services [18-20]. Moreover, efficiency gains can create rebound effects if digital convenience encourages additional movement or consumption rather than lower-impact choices [21]. These countervailing mechanisms justify the present model, which examines when sustainability perceptions are translated into behaviour and why that translation may be stronger for some tourists than for others.

1.2 Technology readiness

TR reflects the extent to which individuals are inclined to embrace and use new technologies to accomplish goals. In tourism, TR shapes not only whether tourists adopt smart tourism technologies, but also how effectively they can use these tools to navigate destinations, reduce uncertainty, and customise experiences. A growing body of evidence shows that tourists differ in digital confidence, perceived control, and willingness to try new travel technologies, which in turn influences satisfaction and behavioural intentions in smart destinations [12, 13].

Within smart city tourism, TR can be conceptualised as a capability that converts the 'potential' of smart infrastructure into realised behavioural outcomes. For example, a city can provide real-time public transport dashboards, integrated ticketing, and micro-mobility sharing systems, but visitors who are not technology-ready may not use these systems and may default to carbon-intensive choices. Conversely, technology-ready tourists are more likely to engage with eco-apps, scan QR-based interpretation, accept digital nudges, and plan routes that balance convenience with sustainability [9, 10].

TR is also conceptually linked to perceived behavioural control, a key mechanism in many behaviour models. When tourists feel competent using smart systems, they perceive sustainable choices as easier, reducing psychological and practical barriers [22, 23]. This aligns with digital sustainability research showing that digital solutions can promote sustainable development when users perceive them as usable, reliable and supportive of meaningful goals [11, 24].

In this study, TR is not only treated as an antecedent of sustainable behaviour (because technology-ready tourists can access enabling tools), but also as a moderator that shapes the strength of the sustainability–behaviour relationship. In other words, sustainability perceptions are expected to lead to stronger PEB among tourists with higher TR, as these tourists can translate perceptions into concrete actions through smart services [10, 13].

1.3 Place engagement

In the present study, PENG refers to an active, visit-specific state of cognitive attention, emotional involvement, and behavioural participation directed toward Kuala Lumpur as a destination [25, 26]. It is related to, but distinct from, place attachment and psychological ownership. Place attachment refers to a more enduring affective bond with the place, whereas psychological ownership captures a felt sense that the place is "mine" and therefore deserves care, stewardship, or protection [14, 27]. We focus on engagement because urban tourists often develop meaningful yet relatively short-term connections through exploration, interaction, and digitally mediated experiences rather than through deep or enduring bonds. In a smart city setting, this action-oriented construct is theoretically appropriate because it captures the degree to which visitors notice, interpret, participate in, and become involved with the place during the visit, which is the psychological state most proximal to pro-environmental action.

PENG is particularly relevant in urban destinations where tourists interact with local communities, everyday mobility systems, cultural institutions, and public spaces. Urban tourism experiences that encourage participation—such as heritage exploration, local food engagement, community events, and cultural learning—can foster place meaning and attachment. When tourists see themselves as 'temporary citizens' rather than passive consumers, they are more likely to reduce negative impacts and comply with environmental rules [15].

From a stimulus–organism–response perspective, sustainability cues and smart services (stimuli) can enhance engagement (organism) by making the city legible, navigable, and personally relevant. Digital layers can deepen engagement by enabling storytelling, personalisation, and co-creation [2]. At the same time, PENG can bridge the attitude–behaviour gap, because engagement provides an affective and identity-based reason to act consistently with sustainability norms [14, 16].

In this study, PENG is modelled as both an outcome of PSS and as a direct predictor of PEB. Furthermore, it is proposed as a mediator that explains how sustainability perceptions are internalised and translated into action. This is consistent with recent moderated-mediation work demonstrating that engagement and destination bonds can transmit the effect of experience quality and creativity to environmentally responsible behaviour among younger cohorts [15].

2. LITERATURE REVIEW

2.1 Perceived sustainability of smart city tourism and pro-environmental behaviour

PEB in tourism has been examined through multiple lenses, including norm activation, value–belief–norm mechanisms, and experience-based models. In smart city tourism, an emerging consensus is that sustainable behaviour is more likely when tourists both (a) perceive sustainability as a salient destination attribute and (b) experience low friction in performing sustainable actions. PSS can raise the moral and social salience of environmental conduct: tourists are more likely to sort waste, use public transit, or reduce single-use plastics when they believe the destination actively supports such practices [6, 10, 11].

PSS can also shape eco-destination image, which has been shown to influence behavioural intentions and concrete

actions. PSS can also shape the environmental image of the destination, and a more positive environmental image has been linked to stronger tourist PEB in situ [7]. Digitalisation may further strengthen these mechanisms by providing transparency into information, simplifying eco-choices, and enabling real-time feedback. For example, tourists who perceive the tourism sector as digitally advanced may also perceive stronger sustainability potential and adjust their personal sustainability behaviours [13].

In urban settings, perceptions of sustainability are also linked to infrastructure and institutional trust. When tourists see reliable public transit, safe pedestrian routes, and clear environmental signage, they interpret sustainable behaviour as feasible. Conversely, when sustainability systems are absent or poorly communicated, tourists may rely on convenience choices, even if they hold pro-environmental attitudes. Research emphasises that sustainable tourism outcomes depend on how tourists, infrastructure, and institutions interact [24].

Based on this literature, the present study expects that when tourists perceive Kuala Lumpur's smart city tourism as sustainable through visible green mobility options, smart waste management, and digital information supporting low-impact choices—they will demonstrate higher PEB during their visit. Therefore, we propose the following hypothesis:
H1: PSS positively influences tourists' PEB in Kuala Lumpur.

2.2 Perceived sustainability of smart city tourism and place engagement

PENG is shaped by how tourists interpret and emotionally respond to destination cues. Sustainability cues can enhance the perceived 'quality' and moral attractiveness of a place: when a city appears to protect its environment and manage tourism responsibly, visitors may feel more respect, trust, and admiration for the destination. This can increase cognitive attention (noticing local systems and culture), emotional connection (feeling proud to visit), and behavioural involvement (participating in local experiences) [14, 16].

In smart destinations, digital systems can further shape engagement by increasing legibility and participation. Smart tourism platforms can offer storytelling, personalisation, and community interaction, deepening engagement beyond consumption. At the same time, the PSS of these systems may matter. Digitalisation that is perceived as wasteful, intrusive, or inequitable can reduce engagement; in contrast, digital solutions framed as supporting sustainability and well-being can enhance tourists' positive appraisal and psychological connection [2, 3, 13].

Empirical studies on sustainable tourism indicate that perceived destination sustainability can foster stronger destination attachment and positive memories, which are antecedents of engagement and revisit behaviour. This suggests that sustainability is not only a functional attribute, but also part of the symbolic meaning of place [15, 28]. In Kuala Lumpur, visible sustainability measures such as transit connectivity, walkability improvements, and environmental information systems may strengthen tourists' sense that the city is modern, caring, and worth connecting to.

Based on these arguments, we propose that tourists who perceive Kuala Lumpur's smart city tourism as sustainable will report higher PENG. Therefore:
H2: PSS positively influences tourists' PENG in Kuala Lumpur.

2.3 Place engagement and pro-environmental behaviour

A substantial stream of recent tourism research supports the link between PENG/attachment and PEB. Place attachment theory suggests that when tourists feel emotionally connected to a destination, they are motivated to protect it. Engaged tourists may refrain from harmful behaviours, comply with environmental regulations, and participate in stewardship actions because the destination becomes part of their self-concept and moral concern [14, 16].

Empirical evidence across diverse destination types indicates that engagement and destination bonds promote environmentally responsible behaviour and eco-tourism behaviour, often through mediators such as satisfaction, awe, perceived value, and moral emotions. Studies using moderated mediation designs further show that destination bonds can transmit experiential effects to eco-behaviour, with individual differences such as ecocentrism strengthening the relationship [15].

In smart city tourism, engagement can be reinforced through technology-enabled participation. Visitors who are engaged may use smart platforms to explore cultural sites, access interpretive content, and interact with local communities, which can increase their awareness of the city's environmental limits and their role in maintaining urban quality of life. Thus, engagement is expected to be a proximal predictor of PEB in Kuala Lumpur, including sustainable mobility, waste reduction, and respect for public spaces [2, 29].
H3: Tourists' PENG positively influences their PEB in Kuala Lumpur.

2.4 The mediating role of place engagement

Research increasingly suggests that sustainability perceptions often require a psychological 'bridge' to generate behaviour, because perceptions can remain abstract unless they trigger personally meaningful motives. PENG is one such bridge because it transforms sustainability cues into an emotional and identity-based commitment to the destination. When tourists perceive a city as sustainable, they may feel that the place aligns with their values and offers a positive moral identity experience, which increases engagement and, subsequently, stewardship behaviours [14, 15].

Recent studies demonstrate mediated pathways linking destination sustainability attributes to responsible behaviours through intermediate psychological states such as place attachment, destination bonds, satisfaction, and memory. These mediated models address the attitude–behaviour gap by identifying how perceptions become internalised and enacted [15, 28]. In the context of Kuala Lumpur, sustainability perceptions may foster engagement with the city's multicultural identity and urban experience, motivating tourists to choose actions that protect public goods such as cleanliness, walkability, and air quality. Therefore, we propose that PENG mediates the relationship between PSS and tourist PEB. Specifically:
H4: PENG mediates the relationship between PSS and tourists' PEB in Kuala Lumpur.

2.5 The moderating role of technology readiness

Even when tourists perceive a destination as sustainable, they may not act accordingly if sustainable options are

perceived as inconvenient or difficult. TR can reduce this barrier by enabling tourists to use smart services that make sustainable behaviours easier. Digital tourism research shows that the effectiveness of digital sustainability solutions depends on user readiness and capability. Technology-ready tourists are more likely to adopt eco-travel apps, accept digital nudges, and utilise integrated smart mobility systems that reduce the effort of sustainable behaviour [10, 13].

In sustainability research, the role of technology has been highlighted in areas such as digital monitoring, smart waste systems, and AI-enabled services that support sustainable development. Yet, individual differences in readiness can shape whether these tools actually influence behaviour. For instance, research on security and sustainability in tourist destinations suggests that digital technologies contribute to sustainable outcomes when tourists interact with them effectively and trust their utility [11]. Similarly, studies on digital solutions for sustainable tourism emphasise that digital tools create value when they are integrated into everyday decision-making by users [24].

TR is conceptualized as a direct predictor and as a moderator since the two roles represent various theoretical roles. Being a direct predictor, TR provides a baseline of digital capability that can in turn stand up on its own and assist tourists to identify routes, access ticketing systems, consume QR-mediated information, and react in response to sustainability cues throughout the visit. TR as a moderator measures conversion efficiency, i.e., how positive sustainability perceptions can practically be translated into behaviour using smart urban systems. This two-fold specification is desirable to considering TR as a segmentation variable per se, since the current argument is about both differences between tourist capabilities across tours, and the conditional performance of destination-level sustainability cues. Digital profile segmentation is useful in future studies, although it should not be used in lieu of studying the actual behavioural mechanism.

H5: TR positively moderates the relationship between PSS and tourists' PEB in Kuala Lumpur.

2.6 Research gap

Although smart tourism research has grown rapidly, three gaps remain salient. First, many smart tourism studies focus on technology adoption outcomes such as use intention, satisfaction, and revisit intention, while treating sustainability as a background narrative rather than as an outcome to be explained. Recent state-of-the-art reviews stress the need to connect smart destination development to sustainability indicators and behaviour-level outcomes [3, 13].

Second, studies of sustainable tourism behaviour often emphasise values, norms, and moral obligations but under-specify how smart infrastructure and digital services alter behavioural opportunity structures in cities. Emerging studies indicate that digitalisation can encourage sustainable behaviour, but its effects depend on contextual and individual factors [10, 24]. There is limited integrative modelling that explicitly combines PSS in a smart destination with individual digital capability and psychological engagement mechanisms.

Third, the empirical evidence remains geographically concentrated in East Asian and European settings, while Southeast Asian metropolitan destinations remain comparatively underexamined despite their rapid digitalisation and intense urban mobility pressures. This matters because the behavioural opportunity structure of an urban tourist visit is shaped not only by values and destination image, but also by transport intermodality, first mile and last mile conditions, and the usability of smart service infrastructure [8, 29]. Kuala Lumpur therefore provides an analytically useful setting for testing whether sustainability perceptions, engagement, and TR jointly explain pro-environmental tourist behaviour in a dense multicultural city.

To address these gaps, we proposes an integrated Partial Least Squares Structural Equation Modelling (PLS-SEM) model with mediation and moderation. PENG is theorised as the mechanism linking sustainability perceptions to behaviour (H4), while TR is proposed as a boundary condition that strengthens the sustainability–behaviour relationship (H5). Figure 1 presents the proposed theoretical model.

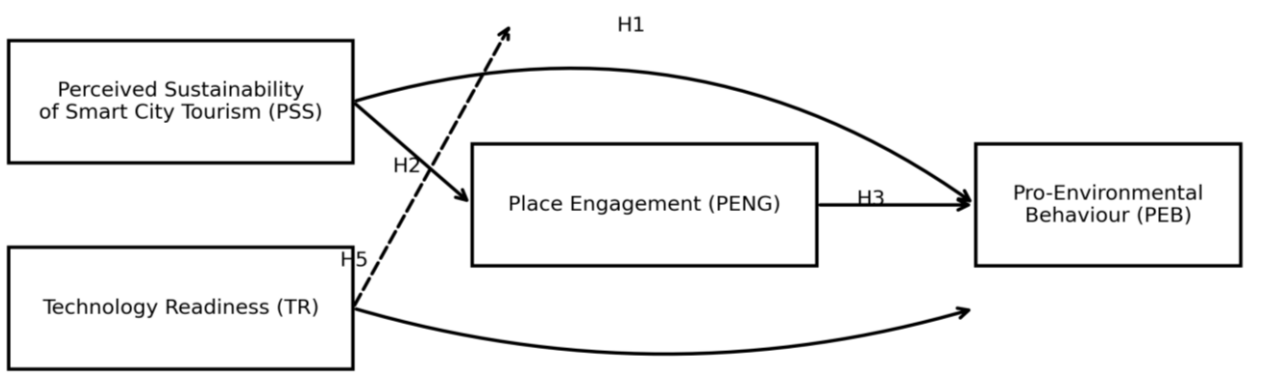

Figure 1. Theoretical model

3. METHODOLOGY

3.1 Research design

The study employed a cross-sectional quantitative design to test an explanatory model integrating sustainability perceptions, PENG, and TR in a smart city tourism context. To match contemporary reporting practices in tourism and sustainability research, the quantitative hypotheses were analysed using PLS-SEM, which is suitable for prediction-oriented models with mediation and moderation and for handling complex measurement structures [30]. Following best practice guidance, the analysis reports measurement reliability, convergent validity (average variance extracted (AVE)), discriminant validity (HTMT), and bootstrapped structural paths [31].

3.2 Study context

Kuala Lumpur was selected because it represents a theoretically relevant smart city tourism setting in which digital governance ambitions intersect with unresolved sustainability pressures. Dewan Bandaraya Kuala Lumpur's smart city agenda explicitly links tourism experience through technology with smart mobility, smart waste management, smart pollution control, and city data analytics, while the city's traffic planning framework identifies continuing congestion, limited public transport interconnection, and first mile and last mile access as major barriers to mobility transition [4, 5]. These characteristics make Kuala Lumpur suitable for examining whether PSS, PENG, and TR jointly explain tourist PEB in a dense, high-mobility, digitally mediated urban destination.

3.3 Research sampling

The intended field protocol uses on-site intercept and QR-assisted surveys in high-tourist-flow locations (KLCC precinct, Bukit Bintang corridor, Central Market, heritage districts) combined with online distribution through accommodation partners. Respondents are tourists aged 18 or older who stayed in Kuala Lumpur for at least 1 day. Participation is voluntary and anonymous, with informed consent presented at the start of the survey.

Data were collected from tourists in Kuala Lumpur through a field survey. Respondents were aged 18 years or older and had stayed in Kuala Lumpur for at least one day. Participation was voluntary and anonymous, and informed consent was obtained at the start of the survey. The final valid sample comprised 420 responses, which were used for the measurement and structural model analyses reported in this study.

3.4 Measurement and questionnaire design

All constructs were measured using multi-item Likert scales (1 = strongly disagree; 5 = strongly agree). Items were adapted from recent tourism and sustainability literature and reworded to fit the Kuala Lumpur smart city tourism context. PSS items captured perceptions that smart tourism services support environmental protection and responsible urban management [10, 13]. PENG items captured emotional connection, cognitive involvement, and behavioural participation in Kuala Lumpur [14-16]. TR items captured confidence, optimism, and innovativeness regarding the use of smart travel technologies [12, 13]. PEB items captured sustainable mobility, waste reduction, and compliance with environmental practices during the visit [6, 15].

3.5 Control and moderation specification

TR was included as an exogenous predictor of PEB and as the moderator of the PSS → PEB path via an interaction term (PSS × TR). All constructs were standardised prior to interaction computation to reduce multicollinearity. Mediation was assessed through the indirect effect PSS → PENG → PEB using bootstrapping, consistent with contemporary SEM recommendations.

3.6 Data analysis

The analysis followed a two-stage approach. First, the measurement model was assessed for indicator loadings, internal consistency reliability (Cronbach's alpha, ρA, ρC), and AVE. Second, discriminant validity was evaluated using HTMT and Fornell–Larcker criteria, in line with current PLS-SEM guidance [30, 31]. Third, the structural model was evaluated using path coefficients (β), bootstrapped t-statistics and p-values (3,000 resamples), effect sizes (f^2), and predictive accuracy measures including R^2 and Q^2 predict with cross-validated RMSE/MAE.

3.7 Questionnaire profile

Table 1 below is the questionnaire profile applied in this research study.

Table 1. Questionnaire profile

Construct	Indicator	Refs.
PSS	PSS1–PSS5	[10, 13]
PENG	PENG1–PENG5	[14-16]
TR	TR1–TR8	[12, 13]
PEB	PEB1–PEB5	[6, 15]

Note: PSS = Perceived Sustainability of Smart City Tourism; PENG = Place Engagement; TR = Technology Readiness; PEB = Pro-environmental Behaviour.

4. RESULTS

The sample (N = 420) comprised tourists surveyed in Kuala Lumpur. Gender distribution was balanced (Female = 50.5%; Male = 48.6%). Most respondents were between 18 and 35 years old (67.3%), domestic tourists represented 55.0% of the sample, and leisure was the primary travel purpose (68.1%). These characteristics are consistent with the study focus on smart city tourism usage and PEB in an urban destination.

4.1 Variables reliability and validity

Internal consistency and convergent validity were assessed using Cronbach's alpha, Dijkstra–Henseler's rho (ρA), composite reliability (ρC), and AVE. As shown in Table 2, all constructs exceeded the recommended thresholds for reliability (≥ 0.70) and convergent validity (AVE ≥ 0.50), indicating adequate measurement quality [30].

Table 2. Reliability and validity statistics

Construct	rhoA	rhoC	Alpha	AVE
PSS	0.8501	0.8501	0.7791	0.5320
PENG	0.8753	0.8753	0.8211	0.5846
TR	0.8950	0.8950	0.8652	0.5169
PEB	0.8957	0.8956	0.8540	0.6322

Note: PSS = Perceived Sustainability of Smart City Tourism; PENG = Place Engagement; TR = Technology Readiness; PEB = Pro-environmental Behaviour.

4.2 Estimated model

Figure 2 presents the estimated structural model with standardised path coefficients. The model specifies direct effects of PSS and PENG on PEB, a direct effect of PSS on PENG, and the moderating effect of TR on the PSS → PEB path, modelled through an interaction term (PSS × TR).

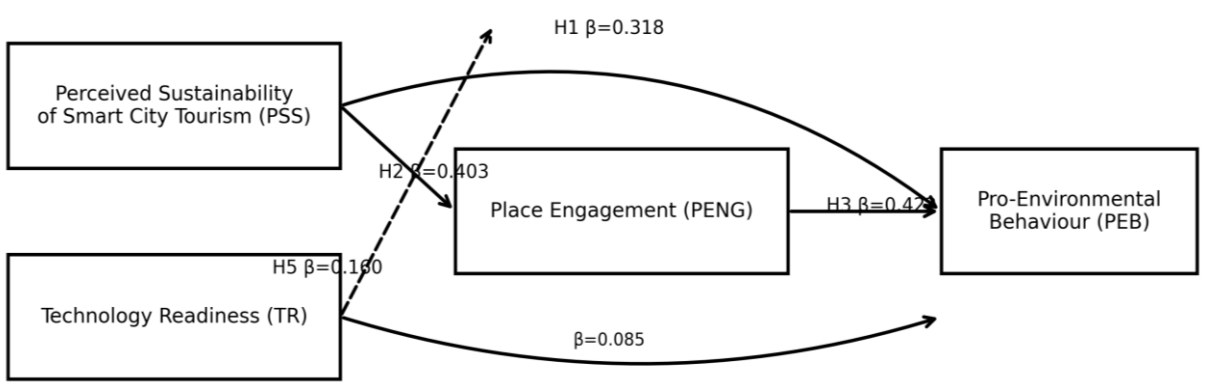

Figure 2. Estimated structural model (standardized coefficients)

4.3 Measurement items fitness statistics

Indicator loadings are reported in Table 3. All indicators loaded on their intended constructs with loadings above 0.65, which is acceptable for exploratory and prediction-oriented models and indicates that indicators are sufficiently associated with their latent variables.

Table 3. Measurement items fitness statistics

Indicator	PSS	PENG	TR	PEB
PSS1	0.7751			
PSS2	0.7600			
PSS3	0.6895			
PSS4	0.7149			
PSS5	0.7038			
PENG1		0.8192		
PENG2		0.7886		
PENG3		0.7749		
PENG4		0.7291		
PENG5		0.7057		
TR1			0.7727	
TR2			0.7914	
TR3			0.7406	
TR4			0.7460	
TR5			0.6734	
TR6			0.6711	
TR7			0.6561	
TR8			0.6875	
PEB1				0.8283
PEB2				0.8292
PEB3				0.7983
PEB4				0.7522
PEB5				0.7645

Note: PSS = Perceived Sustainability of Smart City Tourism; PENG = Place Engagement; TR = Technology Readiness; PEB = Pro-environmental Behaviour.

4.4 Discriminant validity

Table 4. Discriminant validity (HTMT)

	PSS	PENG	TR	PEB
PSS	1.0000	0.5040	0.2712	0.6290
PENG	0.5040	1.0000	0.1889	0.6673
TR	0.2712	0.1889	1.0000	0.2540
PEB	0.6290	0.6673	0.2540	1.0000

Note: PSS = Perceived Sustainability of Smart City Tourism; PENG = Place Engagement; TR = Technology Readiness; PEB = Pro-environmental Behaviour.

Table 5. Discriminant validity (Fornell–Larcker)

	PSS	PENG	TR	PEB
PSS	0.7294	0.4031	0.2227	0.5131
PENG	0.4031	0.7646	0.1592	0.5588
TR	0.2227	0.1592	0.7190	0.2183
PEB	0.5131	0.5588	0.2183	0.7951

Note: PSS = Perceived Sustainability of Smart City Tourism; PENG = Place Engagement; TR = Technology Readiness; PEB = Pro-environmental Behaviour.

Discriminant validity was evaluated using the heterotrait–monotrait ratio (HTMT) and the Fornell–Larcker criterion. HTMT values below 0.85 indicate that constructs are empirically distinct. As shown in Table 4, all HTMT values were below 0.85. Table 5 shows that the square root of each construct's AVE (diagonal) exceeds its correlations with other constructs, further supporting discriminant validity.

4.5 Variables effects overview

Table 6 summarises the direct, indirect, and total effects and Cohen's f^2 effect sizes. PENG demonstrated the largest effect on PEB ($f^2 = 0.266$), followed by PSS ($f^2 = 0.147$). The interaction effect (PSS × TR) showed a small-to-moderate effect size ($f^2 = 0.049$), suggesting meaningful moderation in a behavioural context.

Table 6. Variables effects overview

Relationship	Direct Effects	Indirect Effects	Total Effects	Cohen's f-square
PSS -> PEB	0.3177	0.1701	0.4878	0.1468
PSS -> PENG	0.4031	0.0000	0.4031	0.1941
PENG -> PEB	0.4220	0.0000	0.4220	0.2660
TR -> PEB	0.0845	0.0000	0.0845	0.0121
PSS × TR -> PEB	0.1599	0.0000	0.1599	0.0485

Note: PSS = Perceived Sustainability of Smart City Tourism; PENG = Place Engagement; TR = Technology Readiness; PEB = Pro-environmental Behaviour.

4.6 R-square statistics model goodness of fit statistics

Predictive accuracy was assessed using R^2 and Q^2predict. The model explained 16.3% of the variance in PENG and 44.4% of the variance in PEB. Q^2predict values were positive for both endogenous constructs, indicating predictive relevance. RMSE and MAE values for cross-validated predictions are reported in Table 7.

Table 7. R-square statistics model goodness of fit statistics

Endogenous Variable	R-square	Adjusted R-square	Q-square Predict	RMSE	MAE
PENG	0.1625	0.1605	0.1563	0.9185	0.7682
PEB	0.4441	0.4387	0.4333	0.7528	0.6161

Note: PENG = Place Engagement; PEB = Pro-environmental Behaviour; RMSE = Root Mean Square Error; MAE = Mean Absolute Error.

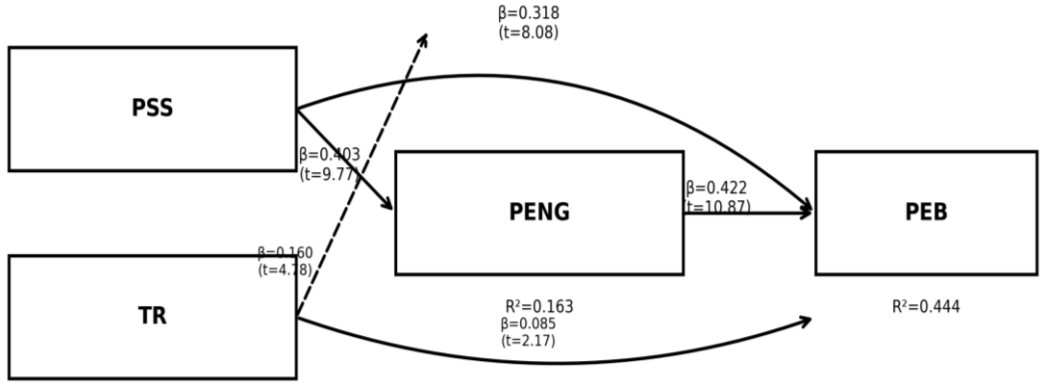

Figure 3. Structural model for path analysis (β and t-statistics)

4.7 Structural model for path analysis

Figure 3 presents the structural model with standardised coefficients and bootstrapped t-statistics. The results indicate that PSS and PENG have significant positive effects on tourist PEB, and that the PSS×TR interaction is significant.

4.8 Path analysis

Bootstrapped path coefficients are reported in Table 8. All hypothesised paths (H1–H5) were supported. The mediating effect of PENG (H4) was significant, indicating partial mediation. The interaction effect (H5) was significant and positive, supporting the moderating role of TR.

Table 8. Path analysis results

Path	Original Sample	St Dev	T Statistics	P Values
PSS->PEB	0.3177	0.0393	8.0810	< 0.001
PSS->PENG	0.4031	0.0413	9.7669	< 0.001
PENG->PEB	0.4220	0.0388	10.8655	< 0.001
Indirect	0.1701	0.0227	7.4846	< 0.001
Interaction	0.1599	0.0334	4.7849	< 0.001
TR->PEB	0.0845	0.0390	2.1673	0.0302

Note: PSS = Perceived Sustainability of Smart City Tourism; PENG = Place Engagement; TR = Technology Readiness; PEB = Pro-environmental Behaviour.

5. DISCUSSION

This paper describes tourist PEB in Kuala Lumpur as a contingent urban process and not a mere byproduct of positive sustainability attitudes. The favourable impact of PSS indicates that visitors view apparent systems of sustainability not just as qualities of a destination, but also as clues as to the types of behaviour that are possible and socially correct in the urban area. This understanding is particularly significant in Kuala Lumpur, where tourist mobility is played out through repetitive choices of mobility in dense areas of tourism and where smart city policy attempts to unload congestion and enable more sustainable patterns of movement.

The mediating effect of PENG shows that cues of sustainability are more behaviourally strong when internalised in a sense of an important relationship with the city. This result aligns with earlier studies that have connected smart tourism experience to place-based psychological connection to environmentally responsible behaviour [6, 8, 14]. But in a metropolitan destination, the current paper proposes that engagement is particularly consequential experience since tourists tend to have the city in small bursts of navigation, interpretation, interaction as opposed to long-term or attachment. Here, PEB signifies the encouragement of this behaviour when visitors shift to being temporary consumers to active users of the location who value urban cleanliness, the effectiveness of mobility as well as the quality of the public space as a common good.

This mediating impact of TR also explains why smart city infrastructure does not necessarily lead to sustainable behaviour. Kuala Lumpur can offer digital forays to the action of lower impacts, but digital forays can be only behaviourally effective when the tourists are prepared to exploit them with a positive attitude and a low perceived effort. This is one of the reasons why one should not judge smartness based on the presence of technologies. Its sustainable worth is determined by the presence of friction at the point of decision in digital tools, particularly in situations where visitors experience novel transport systems, various routes, and schedule-bound traveling habits.

Combined, the results render Kuala Lumpur unique rather than just another instance over smart cities due to the fact that it is a city with the implementation of sustainability results within the unresolved urban movement. There is accessibility via rail, enhancements of walkability, online services, and constant congestion. The research thus adds value by demonstrating that to achieve sustainable tourist behaviour in smart cities, the joint availability of plausible destination cues, a dynamic psychological association with place, and adequate digital capacity to respond to the cues are necessary.

In terms of explanatory power, the model accounted for 44.4% of the variance in PEB. For an applied behavioural model in a heterogeneous tourist population, this level of explained variance is meaningful and suggests that the combination of sustainability perceptions, PENG, and digital

readiness provides a useful prediction-oriented explanation of sustainable tourist actions [32]. At the same time, the modest R^2 for PENG (16.3%) indicates that engagement is shaped by additional factors beyond sustainability perceptions, including destination experience quality, cultural affinity, service encounters, and social interactions. This provides a direction for future studies to expand the engagement formation model by incorporating experience and emotion constructs linked to eco-behaviour in tourism [15].

Interpreting the findings for Kuala Lumpur, the results suggest that city-level sustainability investments and communication strategies can directly influence tourist behaviour, but the largest gains may occur when these efforts are paired with engagement-building experiences and user-friendly technology layers. For example, integrating sustainability information into tourism apps and transport platforms can support low-carbon decisions, but the content should be framed in ways that strengthen tourists' attachment to KL (highlighting local narratives about green public spaces, cultural heritage stewardship, and community well-being) [33, 34]. Such a design is consistent with recent smart tourism work emphasising that smartness should be interpreted as a duality of place and technology, where the human meaning of the destination co-evolves with digital infrastructures [2, 3].

6. CONCLUSION

This manuscript examined PEB in smart city tourism by modelling the interplay of PSS, TR, and PENG in Kuala Lumpur. The results support a model in which PSS increases tourist PEB both directly and indirectly through PENG, while TR strengthens the sustainability–behaviour link via a significant interaction effect. Together, these findings suggest that smart city tourism can contribute to sustainability outcomes when visitors perceive sustainability as salient, feel engaged with the destination, and are ready to use smart tools that reduce the friction of sustainable choices. Conceptually, the study reinforces the importance of integrating sustainability and digitalisation in tourism behaviour research. Practically, it points to a combined strategy for smart cities: (1) invest in visible sustainability systems (mobility, waste, green spaces), (2) design technology layers that enable and nudge sustainable choices, and (3) foster tourists' PENG so that sustainability becomes personally meaningful. These insights are relevant for Kuala Lumpur and other metropolitan destinations seeking to develop smart tourism while advancing sustainability targets.

7. IMPLICATIONS OF THE STUDY

This study contributes theoretically by advancing smart city tourism research from a technology-adoption focus toward behaviour-based sustainability outcomes, positioning tourist PEB as a core performance indicator for smart destination initiatives. The findings reinforce engagement-based explanations, demonstrating that PENG not only directly predicts PEB but also mediates the relationship between sustainability perceptions and behaviour, thereby translating perceptions into stewardship actions. Additionally, TR is identified as a key boundary condition that explains heterogeneous behavioural responses to smart sustainability cues. From a managerial perspective, the practical priority in Kuala Lumpur is to reduce behavioural friction in the visitor journey rather than merely increase the volume of sustainability messaging. In high-flow corridors linking rail stations with major tourist areas such as the KLCC area, Bukit Bintang, Central Market, and nearby heritage districts, destination managers should provide multilingual real-time wayfinding that integrates walking times, interchange guidance, and lower-impact route recommendations. Because the city's mobility agenda prioritises greater public transport use and stronger first mile and last mile access, tourist-facing digital systems should make rail, bus, pedestrian, micromobility, and Park and Ride options legible to short-stay visitors who may not be familiar with local transport routines. Visible sustainability cues in the built environment, such as refill points, recycling facilities, shaded pedestrian links, and concise digital prompts, should be paired with place-based storytelling that frames responsible behaviour as contributing to Kuala Lumpur's urban liveability and heritage stewardship. Digital interventions should also minimise data requests, use clear consent language, and prioritise usability across languages and devices. Policy-wise, digital inclusion, usability, and data governance are essential, as accessible interfaces and privacy protection enhance trust and ensure that sustainability benefits are equitably distributed across tourists with varying levels of TR.

8. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This study has several limitations that guide future research directions. First, the study relies on cross-sectional self-reported survey data collected in Kuala Lumpur, which limits strong causal inference and may be affected by social desirability and recall bias. Future studies should combine survey measures with longitudinal, experience-based, or behavioural indicators and should test the model across seasons and visitor segments. Second, the cross-sectional and self-reported design limits causal inference and may involve social desirability bias; incorporating longitudinal, experience-sampling, and objective behavioural data (e.g., transit usage, app logs, waste behaviours) would strengthen validity. Third, the model explains a modest proportion of variance and includes a parsimonious set of predictors; future research should integrate additional psychological, experiential, and contextual factors such as experience quality, emotions, authenticity, perceived crowding, accessibility, and infrastructure conditions. Fourth, boundary conditions beyond TR—such as digital trust, privacy concerns, and algorithmic transparency, should be examined. Fifth, multi-group and cross-city comparative studies across ASEAN destinations can explore segment differences and contextual variability. Finally, experimental, quasi-experimental, configurational, and machine-learning approaches, along with governance and system-level perspectives, can enhance causal testing, segmentation insights, and policy relevance in sustainable smart city tourism.

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