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Customer engagement, innovation, and sustainable consumption: Analyzing personalized, innovative, sustainable phygital products

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ABSTRACT

Purpose: This research explores the relationship between factors that play a crucial role in e-commerce. This research aimed to check the direct relationship between customer engagement, innovation, and behavior of consumers towards phygital products on patronage intention. Furthermore, this study has explored the mediating role of the behavior of consumers toward phygital products and the moderating role of the level of innovation and sustainable consumption on the direct relationship between customer engagement and patronage intention toward phygital products.

Method: This study applied decision tree analysis, structural equation modeling (SEM), and artificial neural networks (ANN) to test all these proposed relationships. The data was collected from 412 Pakistani internet users who used different shopping applications. Moreover, JASP 0.19.0.0 was employed for analysis, and the data was collected on existing scales.

Findings: The findings show that customer engagement, innovation, personalization, and sustainable consumption significantly affect patronage intentions. However, the moderating effect of consumer behavior was not supportive in this study. Decision tree analysis offered a transparent, interpretable framework for comprehending these dynamics, while the neural network model exposed the nonlinear relationships between these variables.

Originality/implications: This study provides new insights into phygital marketing, notably in Pakistan's fast-growing e-commerce sector. The insights can help marketers optimize their strategy in increasingly linked physical and digital experiences.

Introduction

Digital technology has transformed the customer–business connection through the "phygital" products that combine physical and digital interactions. Businesses trying to give more engaging, amusing, and personalized consumer experiences drive this approach's increasing popularity in retail, entertainment, healthcare, and education (Alexander, 2024). With phygital systems, customers may effortlessly interact with objects in physical and virtual environments (Patil et al., 2024). The approach blends physical and emotional interaction with digital technology's simplicity and customization to enhance consumer experience (Patil et al., 2024). Effective marketing, innovation, and consumer engagement depend on the awareness of consumer behavior and intention to purchase phygital products (Khalid, 2024). The transition to physical commodities is facilitated by augmented reality (AR), virtual reality (VR), and the Internet of Things (IoT), which enable businesses to produce more engaging and dynamic experiences (Mishra et al., 2024).

Although IoT devices can monitor the operation and maintenance automatically, AR applications allow customers to preview the product in their homes before purchasing (Sharma et al., 2024). Also, technological advancement increase the value of customer satisfaction with

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products as it provides businesses with invaluable insights into what people want and how they want it so that products can be adjusted accordingly (Hagen et al., 2024). However, the growth in demand for such an experience and the presence of e-commerce have also increased the demand for tangible products (Pires et al., 2024). Some degree of indolence align with customers' desire for extended brand experiences by incorporating physical entities into spatial interfaces (Mishra et al., 2024). Understanding how customers become engaged and how their intend to patronize in a fast-paced phygital context is essential. This study has moved from looking at the impact of digital technology on consumer behavior to exploring the roles of digital and physical interactions on consumer behavior. The current body of research needs to explain how physical products are engaging for consumers or how they promote loyalty and customer service (Hagen et al., 2024).

Numerous studies have been conducted on consumer behavior, personalization, innovation, and customer engagement for physical and virtual goods (Aziz & Alam, 2024; Dasgupta, 2023). Pires et al. (2024) and Sharma et al. (2024) argue that customer engagement, which refers to conscious attention, affective engagement, cognitive engagement, and enthused participation exhibited by customers toward companies, is the fundamental basis for brand loyalty and purchase intentions. Engagement and emotional relationships between consumers and brands boost satisfaction, repeated purchases, and word-of-mouth (Hagen et al., 2024; Sakas et al., 2024). Brunello (2024) established a relationship between customer engagement and brand loyalty since an engaged customer feels the brand is an expression of themselves. Phygital solutions combine physical and digital interfaces, which help firms interact with customers in both cognitive and affective dimensions (Banik & Gao, 2023).

Moreover, personalization increases client engagement and behavior, which matches products and services to consumer demands and increases brand value, customer satisfaction, and loyalty (Pangarkar & Shukla, 2023). Zafar et al. (2023) discovered that customized marketing messages and product recommendations increase customer engagement, conversion, and loyalty. Therefore, phygital product integration modifies virtual and physical interfaces, improving consumer experience (Patil et al., 2024). Additionally, eco-friendly consumption is linked to brand loyalty, innovation, and consumer behavior (Brun, 2023). Research shows buyers value sustainability and are willing to pay more for products that represent their environmental and social values (Miller et al., 2022; Pangarkar et al., 2023). Pangarkar et al. (2023) found that sustainable brands have more loyal customers, and sustainable practices can boost customer involvement and behavior, especially for phygital items. Alesanco-Llorente et al. (2023) discovered that digitally savvy consumers interact more with phygital items, improving engagement and consumption, and phygital products need consumer behavior analysis to engage and retain customers.

Particularly for phygital products, the literature needs to include more on customer engagement, innovation, customization, and sustainable use (Hagen et al., 2024). The mediating and moderating impacts of personalization (Sharma et al., 2023) and sustainable consumption on customer engagement and patronage intentions have received little attention (Gao & Jiang, 2024). Though in terms of how they interact with customer engagement to drive long-term loyalty and patronage, especially in hybrid products with physical and digital features, it is still being determined whether personalization and sustainability influence consumer behavior (Pires et al., 2024). More research on customer interaction with phygital products is required, given companies' increasing use of these technologies across sectors (Pangarkar et al., 2022). The impact of customization and sustainable consumption on engagement and patronage intentions has yet to be fully understood in the literature (Hyun et al., 2022). While personalization makes interactions more meaningful and gratifying, there is little data on how these tailored experiences translate into long-term loyalty, especially for phygital products (Lawry, 2022). Though the mechanisms by which sustainable consumption influences engagement and patronage intentions remain uncertain, it has been linked to brand loyalty (Mishra et al., 2024).

Research has also understudied the function of consumer behavior as a mediator in the link between customer engagement and patronage intentions toward phygital products (Hagen et al., 2024). A Limited number of studies focus on how consumer behavior impacts phygital products, while most have concentrated on the shift in engagement strategies in light of such behavior (Pires et al., 2024). This gap is significant because phygital products require consumers to interact with physical and digital elements. Understanding the response of different consumer groups to hybrid events will help companies adjust their participation strategies to maximize patronage intentions (Zafar et al., 2023). Although sustainability has been highly studied in consumer products, research into how it impacts behavior in other domains is much needed, particularly those that involve complex hybrid products (Pangarkar et al., 2023). By closing such gaps, companies will better understand customer behavior towards phygital products and how to use these strategies across sectors (Alexander, 2024).

This has been the backbone of consumer behavior and marketing theories, including the theory of planned behavior, the technology acceptance model, and stimulus-organism-response (Duffett et al., 2023; Haider & Ahmed, 2023). According to Lawry (2022), subjective standards, attitude, and perceived behavioral control explain motivation to accomplish something. It implies that phygital product consumer involvement and behavior are influenced by technological, creative, innovation, social, and environmental elements. Furthermore, the technology acceptance model posits that the perception of technology's usability and simplicity has a role in shaping its adoption and engagement (Parolin et al., 2024; Sharma et al., 2022). As a result, it encourages the utilization of technology and the engagement of consumers. TAM explains that customization can make phygital goods more relevant and suitable for consumers; people are more likely to use phygital devices if they see them as easy to use and beneficial (Banik, 2021). To strengthen the theoretical underpinnings of this study, the present research employs established models on engagement, personalization, and sustainable consumption within a hybrid or "phygital" consumer environment. Studies conducted in other regions have shown how awareness about sustainability and experience personalization can be critical in formulating consumer loyalty and brand commitment in multiple digital and physical shopping channels (Brun, 2023). Still, gaps exist in the literature on how these elements interact in emerging market countries, such as Pakistan, which are witnessing a rapidly changing retailing scenario through digitalization. Most previous studies also work with linear consumer engagement models and barely explore the nonlinear dynamics that would more appropriately mirror the consumer's decision-making process in hybrid settings. This study fills in the identified gaps by applying SEM-ANN and provides insights into the nuanced effects of engagement, personalization, and sustainability in Pakistan's e-commerce sector.

Literature review

Consumers are demanding more immersive and captivating experiences, so product marketing, including digital and physical elements, is growing in popularity (Kumar et al., 2024). This "phygital," or hybrid approach, dynamically and individually blends the digital and physical realms. Phygital marketing assists businesses in fusing in-person and virtual encounters to fortify client interactions while seeking distinctive experiences (Bonfanti et al., 2023). Companies may enhance client journeys by offering tailored, innovative, real-time AR, VR, and IoT experiences (Banik & Gao, 2023). These interactions attract the customer and develop brand loyalty by offering simplicity, personalization, innovation, and novelty that no print and digital media can compete with (Harrington, 2023). In physical marketing, multisensory events are utilized in controlling consumer behavior. Evidence reveals that combining physical and digital touchpoints increases the novelty

and involvement of the customer's engagement (Batat, 2024). AR in retail bridges the gap between in-store and online shopping as the clients view products in their actual location (Boudri et al., 2024). Digital kiosks in the real world provide customer-specific recommendations through user information, leading to more unique purchase behaviors (Alexander, 2024). Since it can be used in different areas or industries and particular consumer markets, physical marketing can be a versatile resource for any marketer. Digital strategies may impact the engagement of consumers as companies develop more ways to talk to their customers (Khalid, 2024).

Moreover, the tangible products' physical and technological contact with customers may affect their satisfaction with the brand and buying behavior (Pires et al., 2024). Consumer behavior studies reveal that consumer involvement will considerably impact new technologies and hybrid experiences (Brunello, 2024). According to Brunello (2024), studies have also observed that with higher levels of relationship between a firm and its customers, there is an increase in word-of-mouth marketing, frequency of purchase, and brand loyalty. According to Patil et al. (2024), digital and physical elements introduce phygital products, improving customer contact by being more innovative, personalized, and engaging. In other words, businesses with increased emotional bonds tend to make customers more inclined to patronize them (Alesanco-Llorente et al., 2023; Yi et al., 2025). Other evidence that supports the fact that happy customers are likely to make repeat purchases includes studies on how augmented reality apps and interactive in-store displays raise customer satisfaction and loyalty (Alesanco-Llorente et al., 2023; Pangarkar & Shukla, 2023). As Sharma et al. (2023) agree, "customers' buying propensities of physical products may change according to the degree of their engagements." The hyphenated nature of physical and digital holding allows for multi-dimensional customer engagement; therefore, phygital products offer a better brand experience (Pires et al., 2024). Personalization, innovation, and real-time feedback make physical products more engaging and likely to motivate consumers to repurchase. Hyun et al. (2022) find that consumers who interact more with the company become closer to the latter and feel happier with its service, thus increasing their probability of being loyal for a more extended period and repeating businesses (Sharma et al., 2022). Since consumers grow more brand-dependent, better customer engagement with phygital products could boost brand loyalty.

H1. Customer engagement significantly influences the consumer's patronage intention towards phygital products.

Customer engagement has often been shown to affect both sustainable consumption and personalization (Banik, 2021). Engagement drives consumer desire for tailored goods and services, often reflecting the depth of the consumer-brand relationship. Bonfanti et al. (2023) say highly involved consumers want tailored items. Engaged consumers are more likely to react favorably to tailored marketing initiatives, including product recommendations and communication, raising satisfaction and loyalty (Harrington, 2023). Sustainable consumption also depends critically on engagement. Deeply involved consumers are more likely to adopt sustainable buying behaviors since they identify with the brand's values, innovation, and environmental aims similar to theirs (Batat, 2024). Usually, sustainability and engagement are connected through marketing strategies that highlight the business's environmental friendliness, motivating consumers to adopt greener choices (Patil et al., 2024). Customers wanting personalized experiences typically prefer products and services representing their beliefs, including sustainability (Hagen et al., 2024). As firms integrate sustainable practices into their services, engaged customers will likely choose them as an extension of their personalized experience (El Samra et al., 2023; Mishra et al., 2024). Engagement encourages innovation, personalization, and sustainable consumption as customers strive to connect their choices with their beliefs and preferences (Aziz & Alam, 2024). Customer engagement affects sustainable consumption because engaged customers are more inclined to support the brand's sustainability efforts (Banik & Gao, 2023; Sakas et al., 2024). Engaged customers are more aware of and sensitive to the brand's sustainability efforts, such as eco-friendly products, sustainable packaging, and ethical sourcing (Banik & Gao, 2023).

Moreover, customers feel more aligned with the brand vision and values, hence their commitment to sustainable purchase (Zafar et al., 2023). Thus, engaged customers will be more willing to buy recycled products from environmentally and socially responsible firms. Engagement feeds personalization and sustainability in a virtuous circle because highly engaged customers seek personalized, sustainable products and those products in turn foster brand loyalty (Brun, 2023). Therefore, increased customer engagement will enhance personalization for sustainable consumption by engaging with a brand by making purchases aligned with their beliefs and interests.

H2. Customer engagement significantly influences the consumer's level of innovation and sustainable consumption.

Personalization has conventionally been proven to influence consumer behavior, especially in purchase intentions and brand loyalty. Personalized experiences allow the customers to feel understood and valued by the brands, strengthening emotional attachment and patronage intention behaviors (Pangarkar et al., 2023). In this regard, in one study, Hagen et al. (2024) identified that when a particular brand meets the demands of consumers, then consumers are most likely to switch to that particular brand and this creates more repurchases. Personalization helps increase the product's innovation and perceived value, whereby the consumers are most likely to choose it over any other alternative product or service (Gao & Jiang, 2024). The need to personalize phygital products is much higher because such experiences are embedded along the continuous physical and digital dimensions. This can enhance customer satisfaction and repeat business possibilities through cross-interaction across physical and digital touchpoints (Pangarkar et al., 2022).

Sustainable consumption, the purchase of things with less environmental or social impact, is the third-factor influencing consumer behavior. It has also been shown that customers perceive sustainability in purchasing and are willing to pay even more for the products if they reflect social and environmental values (Kummitha, 2023; Lawry, 2022). Yang and Garnier (2022) have shown that ecocentric consumers prefer the consumption of sustainable products, and regular purchases and interest in green products manifest such allegiance. Kumar et al. (2024) also relate brand trust and contentment with sustainable purchase behaviors that support patronage. Banik and Gao (2023) explain that sustainable consumption affects buyer intention in phygital products by embedding sustainability into the physical and digital product experience.

These study results suggest that the intentions of phygital product patronage of customers are highly influenced by sustainable consumption and customization (Johnson & Barlow, 2024). Personalization makes phygital products more valuable and fun, attracting consumers to seek unique experiences (Gao & Jiang, 2024). The possibility of interaction and immersion within the qualities of phygital goods allows for significant customization and enables advertisers to plan original events accordingly (Johnson & Barlow, 2024). Personalization and sustainability inspire consumers to buy phygital products because they address their interests and values (Boudri et al., 2024). Consumers will likely opt for businesses with higher personalization and sustainable consumption levels.

H3. The level of innovation and sustainable consumption significantly influences the consumer's patronage intention towards phygital products.

Personalization and sustainable consumption have been seen in many research studies as methods through which consumer behavior occurs, especially in the way they always moderate the impacts of customer involvement on patronage intentions (Alexander, 2024). Mishra et al. (2024) show that innovation and customization portray how brand-consumer interactions are made more meaningful and relevant, increasing customer engagement and patronage intentions. This is deepened, in particular, through customers' sustainable consumption, which is ethically and environmentally conscious (Pires et al., 2024). Indeed, sustainable products would attract more loyal customers because they align with their belief system. Sustainable consumption and customization have been found to influence customer engagement directly and indirectly by their impacts on patronage intentions (Aziz & Alam, 2024; Dasgupta, 2023).

The current study postulates that customization and sustainable consumption could be predictors influencing consumer engagement in phygital product use. Personalization is required for phygital products that blend digital and physical experiences (Brunello, 2024). Customer engagement makes it very likely that customers will return for personalized experiences that fulfill their needs and desires (Zafar et al., 2023). Personalization offsets the purpose of engagement and patronage by making consumer experiences more relatable and satisfying. Consumers are more likely to be loyal and buy phygital products from brands offering personalized ecological products (Pangarkar et al., 2023). The personalization and sustainability-related aspects make a product build value that depends on customer engagement and loyalty. Personalization and sustainable consumption form a mediator in phygital products, where ethics and individuality are valued by consuming customers (Hagen et al., 2024). The ability to offer unique, personalized, sustainable experiences is the differentiation factor when firms interface with customers through phygital means (Pires et al., 2024). Engaged consumers are more likely to value and implement these original ideas, strengthening brand loyalty and enjoyment (Lawry, 2022). The mediation effect illustrates that with customization and sustainable consumption, customer involvement may significantly affect patronage intentions (Banik & Gao, 2023). Personalization and sustainable consumption probably mediate the relationship between customer engagement and phygital product patronage intention, guaranteeing that engagement advantages are fully fulfilled through customized, sustainable experiences.

H4. Level of innovation and sustainable consumption significantly mediate the relationship between customer engagement and consumer patronage intention towards phygital products.

Empirical research repeatedly shows that consumer behavior moderates the effects of marketing strategies on patronage intention and brand loyalty (Batat, 2024). Consumer impression and product interaction influence how engagement strategies result in brand loyalty (Boudri et al., 2024). Harrington (2023) claims that consumer behavior, mainly how they accept new product forms, may affect efforts at engagement. Consumer behavior is much more critical for phygital products integrating digital and physical interactions (Kumar et al., 2024). Moreover, consumer behavior towards phygital items affects instantaneous reactions and facilitates control of the engagement–patronage intention relationship (Sharma et al., 2022). These findings imply that consumer behavior toward phygital objects can drastically alter the relationship between customer engagement and intention (Pangarkar et al., 2022).

Furthermore, customers who are more at ease with and responsive to digital technology could find phygital products more innovative and appealing, which increases the possibility of them buying the brand (Sharma et al., 2023). However, consumers less familiar or enthusiastic about digital components may interact less, reducing the link between engagement and patronage intention (Pangarkar et al., 2023). Customer interaction tactics can drive patronage intention differently depending on how consumers use phygital products. Customer behavior influences the degree of long-term brand loyalty engagement (Patil et al., 2023). Phygital product interaction tactics are controlled by consumer behavior. Hence, brands must consider it (Banik & Gao, 2023). Positive behavior towards phygital products, that is, regular use of digital interfaces, active engagement in interactive features, or a desire for experiences improved by technology, can deepen brand relationships and raise patronage intentions (Pires et al., 2024). Should customer conduct towards these products be weak or resistant, engagement activities may not produce desired outcomes, compromising the link between engagement and ongoing patronage (Mishra et al., 2024; Piana & Brustolin, 2023). These moderating functions underline the need to customize engagement strategies to fit consumer behavior patterns to improve the link between customer engagement and patronage intention (Sharma et al., 2024). Therefore, consumer behavior towards phygital items significantly reduces the link between customer engagement and patronage intention, influencing the extent of the brand loyalty-building ability of engagement strategies.

H5. The behavior of consumers towards phygital products significantly moderates the relationship between customer engagement and consumers' patronage intention towards phygital products.

Though the earlier studies clearly described the role of involvement and customization in improving customer experience, they overlooked significant limitations, such as the cross-culture adaptability of the involved variables (Mishra et al., 2024; Piana & Brustolin, 2023). Moreover, most of the studies deployed a one-dimensional model, which further limits understanding of complex multi-dimensional consumer behavior within the context of phygital (Batat, 2024). This research fills those gaps by applying a multi-dimensional, nonlinear approach while utilizing SEM-ANN to analyze phygital consumer behavior, providing a more holistic understanding of how these constructs work in multiple cultural environments.

Methodology

Data collection method

This study examined how customer engagement, innovation, personalization, and sustainable consumption affect phygital product patronage intentions, focusing on consumer behavior as a moderator. Users of internet platforms were the focus of this Pakistani study. This research adopted purposive sampling to sample 412 consumers actively using Pakistani e-commerce platforms, such as Daraz and Yayvo. This sampling technique provides insight into the behaviors and preferences of consumers in the digital marketplace. However, this focus creates a bias, as the sample might need to be representative of offline or less tech-savvy consumer segments, which could limit the generalizability of the findings. Future studies could expand the sample to include consumers with varying levels of digital literacy to have a more balanced viewpoint on phygital engagement.

Measurement scales

The findings are relevant to Pakistan's changing phygital marketing landscape. Consumer involvement, personalization, level of innovation and sustainable consumption, consumer behavior, and patronage intentions for phygital products were all measured by a thorough questionnaire. To ensure validity and reliability, the questionnaire scales were based on validated research. In order to fit the elements being studied, these scales were designed for phygital experiences and e-commerce. Table 1 shows the institution's profile with several items and citations.

For methodological rigor, scales for customer engagement, personalization, and sustainable consumption were taken from previous

Table 1
Instruments profile.

Sr. No	Variable	Sub-Variable	No. of Items	Reference of the study
1	Customer Engagement	Conscious Attention	03	(Banik, 2021)
		Cognitive Engagement	03	
		Affective Engagement	04	
		Enthused Participation	03	
2	Patronage Intention towards	Phygital Products	09	(Banik, 2021)
3	Level of Innovation and Sustainable Consumption	Reliability	04	(Saniuk et al., 2020)
		Assurance	03	
		Tangibles	05	
		Empathy	03	
		Responsiveness	03	
4	Behavior of Consumers towards Phygital Products		09	(Ballina et al., 2019)

research and validated for cultural relevance in Pakistani e-commerce. A preliminary pilot test was conducted with 50 participants, ensuring scale reliability and confirming that the constructs held cultural applicability, enhancing the accuracy of our findings within this unique market context.

Data analyses techniques

The analysis used JASP version 0.19.0.0, a statistical tool for investigating SEM and ANN. These methods were selected based on their ability to effectively analyze complex variable interactions and nonlinear patterns. An analysis was conducted to explore potential relationships between variables. In order to gain a more comprehensive understanding of how specific attributes affect these interactions, our model also examined the moderating impact of consumer behavior. An ANN was utilized to analyze nonlinear relationships and variable interactions following the SEM investigation. The ANN model's input layer comprised essential factors, while two hidden layers were included to capture complex patterns. Lastly, an output layer was incorporated to predict patronage intentions. Artificial neural networks enabled the discovery of complex patterns that may have yet to be noticed by traditional statistical methods such as structural equation modeling. Furthermore, a decision tree analysis was conducted to understand the impact of moderating influence and customer contact on consumers' patronage intentions. The decision tree method uncovered the critical decision points that impact consumer behavior in phygital marketing through response-based sample classification.

Results

Multicollinearity

Table 2 represents the validity and reliability tests of the measurement constructs adopted for this study: customer engagement, consumer behavior, personalization, and patronage intention. The metrics used to establish the validity and reliability through AVE, VIF, Cronbach's Alpha, and Composite Reliability employ statistical values such as original sample values, means, standard deviation, T-statistics, and P-values. These measures indicate convergent validity, multicollinearity, and internal consistency of the construct, ensuring that the model is robust and that one is assured of reliable results. Conscious Attention, Cognitive Engagement, Affective Engagement, and Enthused Participation are the four characteristics by which Customer Engagement is measured. The Cronbach's Alpha values of these dimensions are 0.864–0.891, showing good internal consistency. Composite dependability results of 0.928 for Conscious Attention and 0.925 for Affective Engagement exceed the threshold of 0.7, showing construct dependability. The AVE values above 0.7 show that constructs capture much variation rather than error variance, validating the model's convergent validity. T-statistics and P-values for all indicators are highly significant ($P < 0.0000$), and VIF values are below 5, showing no multicollinearity in this model. AE1, the Affective Engagement indicator, has a T-statistic of 36.267 and a VIF of 2.428, indicating vital significance and good multicollinearity, as indicated by Table 2.

Reliability and validity

Table 2 also measures consumer behavior with nine metrics. This construct's Cronbach's Alpha of 0.947 and Composite Reliability of 0.955 indicate internal solid consistency. While slightly lower than other constructs, this construct's AVE of 0.702 satisfies the acceptable level for convergent validity, as shown in Table 2. BC1, BC9, and other indicators in this construct have significant T-statistics (31.884 and 29.095, respectively) and P-values of 0.0000, confirming their statistical significance. Multicollinearity is within acceptable bounds for these markers, as shown by their VIF values of 2.866 for BC1 and 2.706 for BC9. These measurements are reliable. Another vital model construct is the Level of Personalisation, which includes Reliability, Responsiveness, Tangibles, Assurance, and Empathy. This construct is highly reliable, with Cronbach's Alpha values from 0.886 for Reliability to 0.930 for Empathy. Composite Reliability ratings of 0.937 for Tangibles and 0.921 for Reliability demonstrate good consistency across these aspects. All constructs have AVE values above 0.7, indicating that they capture much variance. High T-statistics and P-values (e.g., RE3 with 44.541 and 0.0000) and VIF values (2.657 for RE3 and 2.894 for T3) indicate that multicollinearity is under control. Last, nine indicators with good reliability and validity statistics indicate Patronage Intention. Excellent internal consistency is shown by Cronbach's Alpha 0.962 and Composite Reliability 0.967. The construct's validity is supported by the AVE of 0.766. T-statistics of 48.79 and 44.173 and P-values of 0.0000 indicate substantial statistical significance for PI4 and PI9. PI9′s VIF is 2.846, assuring no multicollinearity, as indicated by Table 2.

Fornell-Larcker criterion – discriminant validity

Table 3 shows the Fornell-Larcker criterion for model construct discriminant validity. Comparing the square root of each construct's Average Variance Extracted (AVE) to the correlations between components confirms discriminant validity (Ahmed et al., 2024). In Table 3, diagonal elements are AVE square roots, while off-diagonal elements are construct correlations. The square roots of the AVEs (diagonal values) are consistently more significant than the correlations (off-diagonal values), showing that each construct shares more variance with its indicators than others. Affective Engagement has a square root of AVE of 0.868, more significant than its associations with Consumer Behaviour and Customer Engagement, which are 0.842 and 0.854, respectively. This proves that the model's constructs are separate and discriminant.

Heterotrait-Monotrait (HTMT) ratio – discriminant validity

Table 4 shows the Heterotrait-Monotrait (HTMT) ratio, another discriminant validity measure. The HTMT criterion compares construct correlations and recommends values below 0.85 for discriminant validity. However, some researchers allow values up to 0.90 (Ahmed et al., 2024). In Table 4, HTMT values range from 0.746 to 0.896, with most values within acceptable criteria, indicating that the constructs are unique enough. Affective Engagement and Assurance have an HTMT of 0.865, whereas Customer Engagement and Patronage Intention have 0.877. These values are high but within the acceptable range, showing that the model meets discriminant validity standards, albeit closely.

Table 2
Estimated model reliability and validity.

	Variable	Indicator	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values	VIF	Cronbach's Alpha	Composite Reliability	Average Variance Extracted
Customer Engagement	Customer Engagement								0.961	0.966	0.683
	Affective Engagement	AE1	0.871	0.868	0.024	36.267	0.0000	2.428	0.891	0.925	0.754
		AE2	0.863	0.86	0.026	33.729	0.0000	2.309			
		AE3	0.858	0.855	0.025	34.22	0.0000	2.251			
		AE4	0.881	0.879	0.021	42.535	0.0000	2.568			
	Conscious attention	CA1	0.919	0.918	0.014	67.667	0.0000	2.966	0.884	0.928	0.812
		CA2	0.904	0.902	0.017	54.021	0.0000	2.678			
		CA3	0.88	0.878	0.02	45.075	0.0000	2.18			
	Cognitive Engagement	CE1	0.883	0.88	0.024	37.394	0.0000	2.251	0.871	0.921	0.795
		CE2	0.912	0.911	0.015	61.301	0.0000	2.66			
		CE3	0.878	0.876	0.021	41.955	0.0000	2.171			
	Enthused Participation	EP1	0.879	0.877	0.021	41.139	0.0000	2.172	0.864	0.917	0.786
		EP2	0.887	0.885	0.02	43.405	0.0000	2.216			
		EP3	0.893	0.891	0.018	49.572	0.0000	2.268			
	Behavior of consumers	BC1	0.85	0.847	0.027	31.884	0.0000	2.866	0.947	0.955	0.702
		BC2	0.792	0.788	0.038	20.632	0.0000	2.28			
		BC3	0.853	0.849	0.027	31.497	0.0000	2.939			
		BC4	0.863	0.86	0.025	34.803	0.0000	3.363			
		BC5	0.852	0.849	0.024	36.206	0.0000	3.101			
		BC6	0.82	0.816	0.031	26.336	0.0000	2.496			
		BC7	0.828	0.823	0.031	26.336	0.0000	2.645			
		BC8	0.847	0.843	0.027	31.186	0.0000	2.868			
		BC9	0.835	0.831	0.029	29.095	0.0000	2.706			
Level of innovation	Level of Innovation								0.975	0.977	0.7
	Reliability	RE1	0.82	0.816	0.033	25.17	0.0000	1.912	0.886	0.921	0.746
		RE2	0.853	0.85	0.024	35.739	0.0000	2.373			
		RE3	0.887	0.884	0.02	44.541	0.0000	2.657			
		RE4	0.893	0.891	0.019	47.097	0.0000	2.838			
	Responsiveness	RS1	0.893	0.891	0.02	43.599	0.0000	2.369	0.891	0.932	0.721
		RS2	0.917	0.916	0.017	55.265	0.0000	2.878			
		RS3	0.907	0.905	0.017	53.354	0.0000	2.737			
	Tangibles	T1	0.87	0.867	0.024	36.65	0.0000	2.676	0.916	0.937	0.748
		T2	0.875	0.872	0.023	37.377	0.0000	2.939			
		T3	0.872	0.868	0.025	35.498	0.0000	2.894			
		T4	0.863	0.859	0.024	35.3	0.0000	2.558			
		T5	0.844	0.84	0.028	30.22	0.0000	2.327			
	Assurance	A1	0.896	0.894	0.018	49.745	0.0000	2.404	0.883	0.928	0.781
		A2	0.911	0.909	0.016	55.946	0.0000	2.71			
		A3	0.893	0.89	0.02	44.345	0.0000	2.401			
	Empathy	E1	0.951	0.951	0.008	125.515	0.0000	2.769	0.93	0.956	0.787
		E2	0.932	0.931	0.013	69.431	0.0000	2.69			
		E3	0.926	0.924	0.015	61.621	0.0000	3.428			
	Patronage intention	PI1	0.878	0.876	0.023	38.736	0.0000	2.858	0.962	0.967	0.766
		PI2	0.852	0.849	0.025	33.46	0.0000	3.207			
		PI3	0.837	0.834	0.027	30.485	0.0000	3.014			
		PI4	0.895	0.893	0.018	48.79	0.0000	2.871			
		PI5	0.875	0.872	0.022	40.313	0.0000	2.813			
		PI6	0.88	0.879	0.021	41.396	0.0000	2.85			
		PI7	0.891	0.889	0.02	44.044	0.0000	2.55			
		PI8	0.885	0.883	0.019	46.693	0.0000	2.6			
		PI9	0.882	0.88	0.02	44.173	0.0000	2.846			

Model fitness statistics

Table 5 summarises the model's fitness data, including SRMR, d_ULS, and predictive measures like RMSE, MAE, Q^2_predict, and Blindfolding outcomes for certain constructs. Saturated Model and Estimated Model SRMR values are 0.054 and 0.062, respectively, below 0.08, suggesting a satisfactory model fit. The Saturated Model has a d_ULS value of 9.379, indicating the disparity between the empirical correlation matrix and the model-implied correlation matrix. Prediction and blindfolding statistics for Affective Engagement and Patronage Intention show strong relevance, with Q^2 values ranging from 0.541 to 0.705. A Q^2 score of 0.656 indicates the model has strong predictive power for the Level of Personalisation construct, as shown in Table 5.

R-Square and F-Square values

R-Square and F-Square values, shown in Table 6, help determine the model constructs' explanatory strength and effect magnitude (Ahmed et al., 2024). R-Square values range from 0.465 for Conscious Attention to 0.616 for Level of Personalisation, indicating the proportion of variance in dependent variables explained by independent variables. The R-Square value of 0.611 for Affective Engagement shows that the model explains 61.1 % of its variation. The effect magnitude of each predictor variable on the dependent variable is shown by F-Square values. The

Table 3
Fornell-Larcker criterion.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Affective Engagement	0.868												
Assurance	0.795	0.781											
Behavior of Consumers	0.842	0.798	0.838										
Cognitive Engagement	0.810	0.854	0.825	0.795									
Conscious Attention	0.801	0.725	0.814	0.750	0.812								
Customer Engagement	0.854	0.825	0.842	0.871	0.850	0.826							
Empathy	0.815	0.798	0.817	0.810	0.804	0.827	0.787						
Enthused Participation	0.835	0.854	0.830	0.846	0.742	0.844	0.809	0.786					
Level of Innovation	0.828	0.841	0.867	0.836	0.864	0.838	0.810	0.837	0.700				
Patronage Intention	0.815	0.805	0.817	0.811	0.754	0.816	0.808	0.815	0.818	0.766			
Reliability	0.802	0.835	0.807	0.800	0.814	0.825	0.815	0.818	0.825	0.822	0.746		
Responsiveness	0.814	0.835	0.826	0.810	0.798	0.824	0.832	0.823	0.820	0.821	0.841	0.721	
Tangibles	0.821	0.833	0.841	0.826	0.823	0.834	0.815	0.818	0.829	0.822	0.831	0.841	0.748

Table 4
HTMT criterion.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Affective Engagement													
Assurance	0.865												
Behavior of Consumers	0.874	0.871											
Cognitive Engagement	0.870	0.882	0.872										
Conscious Attention	0.858	0.854	0.895	0.810									
Customer Engagement	0.876	0.887	0.877	0.883	0.860								
Empathy	0.850	0.880	0.887	0.875	0.872	0.887							
Enthused Participation	0.878	0.888	0.881	0.879	0.850	0.877	0.867						
Level of Innovation	0.896	0.891	0.886	0.889	0.881	0.890	0.882	0.884					
Patronage Intention	0.877	0.885	0.883	0.887	0.817	0.874	0.870	0.877	0.879				
Reliability	0.880	0.884	0.878	0.882	0.871	0.877	0.873	0.871	0.880	0.866			
Responsiveness	0.876	0.878	0.882	0.874	0.871	0.870	0.875	0.873	0.880	0.871	0.872		
Tangibles	0.873	0.870	0.876	0.874	0.870	0.877	0.875	0.874	0.883	0.877	0.871	0.876	

Table 5
Model fitness statistics.

	Saturated Model	Estimated Model		Prediction			Blindfolding		
SRMR	0.054	0.062		RMSE	MAE	Q^2_predict	SSO	SSE	Q^2 (=1-SSE/SSO)
d_ULS	9.379	12.292	Affective Engagement	0.283	0.225	0.923	1300	552.576	0.575
			Assurance	0.398	0.326	0.848	975	404.33	0.585
			Cognitive Engagement	0.350	0.284	0.882	975	430.845	0.558
			Conscious Attention	0.478	0.390	0.779	975	400.109	0.590
			Empathy	0.459	0.383	0.797	975	287.679	0.705
			Enthused Participation	0.324	0.257	0.899	975	447.073	0.541
			Level of Innovation	0.275	0.218	0.928	5850	2013.87	0.656
			Patronage Intention	0.367	0.298	0.871	2925	883.144	0.698
			Reliability	0.439	0.351	0.815	1300	570.156	0.561
			Responsiveness	0.469	0.384	0.789	975	386.706	0.603
			Tangibles	0.388	0.315	0.856	1625	633.485	0.610

Table 6
R-Square and F-Square values.

	R Square	R Square Adjusted	AE	A	CE	CA	E	EP	LP	PI	R	RS	T
Affective Engagement (AE)	0.611	0.611											
Assurance (A)	0.536	0.535											
Cognitive Engagement (CE)	0.57	0.57											
Conscious attention (CA)	0.465	0.465											
Empathy (E)	0.569	0.569											
Enthused participation (EP)	0.587	0.587											
Level of innovation (LI)	0.616	0.616		5.479			7.257			0.028	8.924	7.779	9.394
Patronage Intention (PI)	0.571	0.569											
Reliability (R)	0.589	0.589											
Responsiveness (RS)	0.576	0.576											
Tangibles (T)	0.594	0.593											
Behavior of Consumers (BC)										0.04			
Customer Engagement (CE)			11.732		7.341	3.451		8.707	12.574	0.094			
Moderating Effect 1 (M)										0.003			

F-Square values for Customer Engagement (11.732) and Level of Personalisation (7.779) are significant. The results of Table 6 demonstrate the model's robustness by showing the primary constructs' great predictive power and significant effects.

Path coefficient analyses

Table 7 presents the route analysis findings for the proposed hypotheses in the study. Table 7 contains the Original Sample mean, Standard Deviation, T Statistics, and P Values of each hypothesis. Hypothesis 1 demonstrates a substantial positive path coefficient of 0.426, supported by a T statistic of 5.709 and a P value of 0.000, thus indicating robust statistical evidence. Fig. 1 also demonstrates the path coefficient analyses.

Similarly, Hypotheses 2, 3, and 4 provide statistically significant outcomes, as evidenced by T-statistics ranging from 2.997 to 8.913 and P-values of 0.003 and, below, showing a substantial degree of confidence in these associations. Nevertheless, Hypothesis 5 exhibits a far less robust path coefficient of 0.030, accompanied by a T-statistic of 1.098 and a P-value of 0.273, indicating that this association lacks statistical significance. In summary, the findings of Table 7 and Fig. 1 provide robust evidence in favor of most of the hypotheses examined in the model.

Model performance and feature significance metrics

Table 8 shows model performance and feature significance metrics. Metrics like MSE, RMSE, MAE, and R^2 are used to assess model performance. The MSE is 0.13 and the scaled MSE is 0.262, indicating a good model error. The RMSE of 0.361, MAE/MAD of 0.304, and R^2 value of 0.752 indicate the model's prediction accuracy and 75.2 % variance explanation. The most crucial factor is the "Moderating Effect," with a mean dropout loss of 0.996, followed by "Behavior of Consumers" (0.867) and "Level of Personalisation" (0.836). Customer Engagement has a lower significance score of 0.547, suggesting other characteristics affect the model's predictions more, as indicated by Table 8.

Additive explanations for predictions of test set cases

Table 9 shows the additive explanations for test set case predictions, broken down by feature. Case 1′s projected value is 0.304, with "Level of Personalisation" providing −0.003, "Moderating Effect" 0.265, and "Customer Engagement" 0.055. In Case 2, the anticipated value is 0.263, with comparable attributes, but "Customer Engagement" is lower at 0.018. In Case 3, "Behaviour of Consumers" has a negative impact (−0.045), lowering the anticipated value to 0.141. Each case's contribution breakdown shows how characteristics affect predictions, emphasizing the importance of factors like "Customer Engagement" and the "Moderating Effect" across cases, as shown in Table 9.

Table 7
Path analysis.

	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values
Hypothesis 1	0.426	0.425	0.075	5.709	0.000
Hypothesis 2	0.329	0.319	0.009	8.913	0.000
Hypothesis 3	0.332	0.333	0.111	2.997	0.003
Hypothesis 4	0.320	0.320	0.106	3.008	0.003
Hypothesis 5	0.030	0.031	0.028	1.098	0.273

The predictive performance plot

The Predictive Performance Plot shows the correlation between actual and expected test scores, as shown in Fig. 2. A red diagonal line shows how the data points are clustered, which means that the predicted and observed values are highly correlated. The fact that the model's predictions are so closely aligned with the observed data implies that they are correct.

The mean squared error (MSE) plot

The Mean Squared Error (MSE) Plot displays the error rates of the training and validation sets across generations. Fig. 3 shows that the MSE for both sets drops at the outset, and by the fourth generation, it has stabilized at its lowest position. As the model continues to learn and generalize with little overfitting, the MSE stays essentially constant after this point.

The logistic sigmoid activation function plot

The Logistic Sigmoid Activation Function Plot (Fig. 4) shows the S-shaped curve defining the link between input and output values. As the input values move from negative to positive, the output linearly moves from almost 1 to near-1. A popular technique in binary classification models for mapping predictions to a probability between 0 and 1, the sigmoid function applies a nonlinear transformation seen in Fig. 4.

The neural network model

This study examined how consumer behavior moderates the effect of consumer engagement, level of customization, and sustainable consumption on patronage intentions toward phygital products using a neural network model, as depicted in Fig. 5. The network has three layers: input, hidden, and output. The four brown square nodes of the input layer—consumer behavior, sustainable consumption, degree of customization, and customer involvement—represent the key factors of the research. Without these inputs, no factors influencing phygital environment customer intentions can be fully appreciated. Two hidden layers enable the network to evaluate these inputs. Comprising five blue circular nodes, the first hidden layer handles the inputs and begins to find trends and correlations between the variables. This layer is fundamental to grasping the interaction among customer involvement, customization, and sustainability. Including the impact of consumer behavior and controlling factors on the overall patronage intention, the second hidden layer—which consists of one blue node—helps to improve this data even more. Finally, the processed data reaches the output layer, symbolized by a green square. The final projection of consumer intentions to buy phygital products is produced by this layer. The intercept (yellow triangle) influences all layers to ensure the model catches the baseline effects of certain variables. When characteristics like personalization and environmentally responsible consumption are considered moderators, the neural network model is essential for understanding the nonlinear links between consumer involvement and intention to purchase in this work. The model captures consumers' decision-making processes about phygital objects using several stages of processing these elements, as indicated by Fig. 5.

Excellent predictive capabilities have been demonstrated in neural networks (Fig. 5), showing it caught very well the relations in terms of complex nonlinear interactions; in this case, by this feature alone, SEM-ANN outweighs more traditional regression models and other less sophisticated approaches such as a series of regression models which include simple moderation models as seen. This is because the complexity of the phygital consumer behavior is fully understood by SEM-ANN, and there are some nuances where personalization and sustainability impact engagement, not provided by linear models.

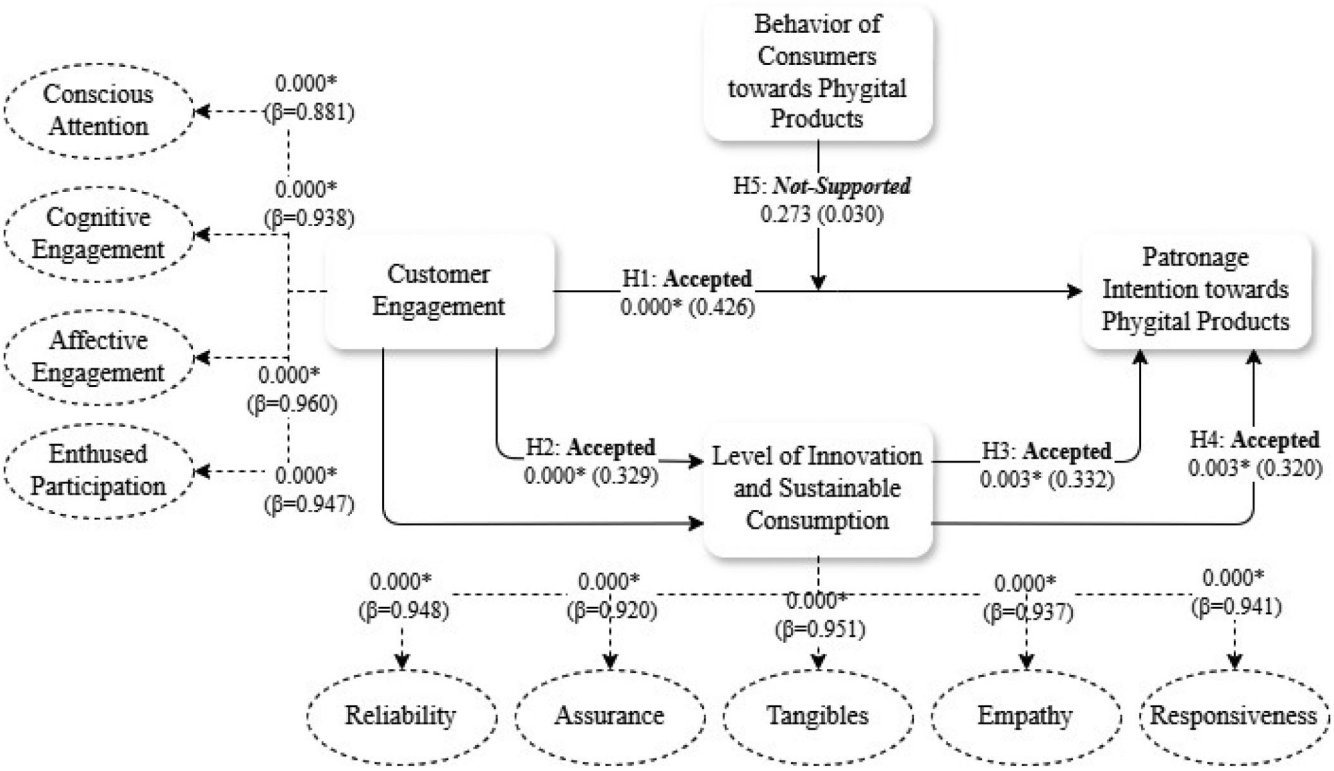

Fig. 1. Path analysis of the study.

Table 8
Model performance and importance metrics.

Model Performance Metrics		*Feature Importance Metrics*	
	Value		Mean dropout loss
MSE	0.13	Moderating Effect	0.996
MSE(scaled)	0.262	Behavior of Consumers	0.867
RMSE	0.361	Level of innovation	0.836
MAE / MAD	0.304	Customer Engagement	0.547
MAPE	153.36 %		
R^2	0.752		

Decision tree plot

As depicted in Fig. 6, the researchers used a decision tree analysis to understand better the factors influencing customers' intentions to purchase phygital products, particularly the moderating effect and customer engagement. The decision tree starts at the "Moderating Effect 1″ root node, which gathers all 208 observations. If the value of the moderating effect is more than or equal to 1.36, the sample is divided at this node, which is the principal decision point. Based on a tiny selection of 12 observations, the tree branches left if the value is above this threshold, ultimately leading to a terminal node with a predicted outcome of −3.550. Alternatively, if the moderating impact is below 1.36, the decision tree proceeds to a different node focused on "Customer Engagement," which involves 196 observations. Whether the level of consumer interaction is less than or equal to 0.472 further categorizes this node. The last nodes of the tree represent predictions for 154 observations with customer engagement < 0.472, 42 observations with higher customer engagement, and the cases above with a high moderating effect, with predictions of 0.542 and −3.550, respectively, for these observations. The statistical values, decision tree plot (Fig. 6), and network structure (Fig. 5) highlight the factors most likely influencing consumers' opinions of phygital products. While the decision tree (Fig. 6) provides a clear, interpretable road for studying moderating effects and customer engagement, multiple neural network layers catch intricate, nonlinear relationships. The consumer behavior of phygital marketing is revealed by these methods together.

The practical implications of such research extend to multinational e-commerce platforms operating phygital models worldwide. The insights from SEM-ANN (Fig. 5) and decision tree analyses (Fig. 6) bring to the fore the relevance of adaptable engagement strategies that could be fitted to local preferences in different markets. Through culturally responsive personalization in these platforms, consumer satisfaction and loyalty would be optimized to meet regional expectations but still operationalized globally.

Discussion

In the rapidly evolving consumer interaction landscape, phygital technologies seamlessly blend physical and digital experiences, allowing marketers to reimagine their customer engagement strategies. Including

Table 9
Additive explanations for predictions of test set cases.

Case	Predicted	Base	Level of Innovation	Moderating Effect	Customer Engagement	Behavior of Consumers
1	0.304	−0.014	−0.003	0.265	0.055	0.002
2	0.263	−0.014	−0.004	0.261	0.018	0.002
3	0.141	−0.014	0.014	0.250	−0.065	−0.045
4	0.253	−0.014	0.024	0.259	−0.020	0.004
5	0.165	−0.014	−0.024	0.251	0.071	−0.120

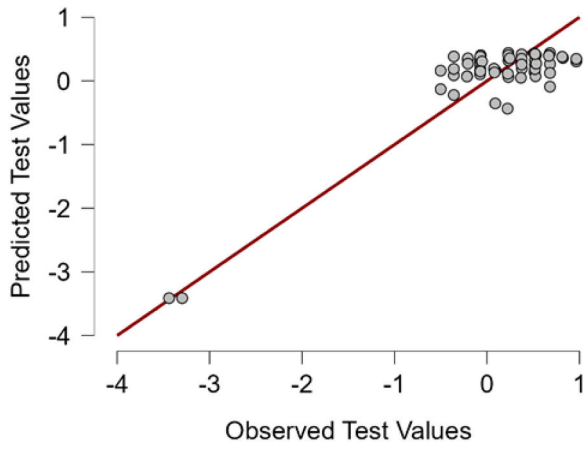

Fig. 2. Predictive performance plot.

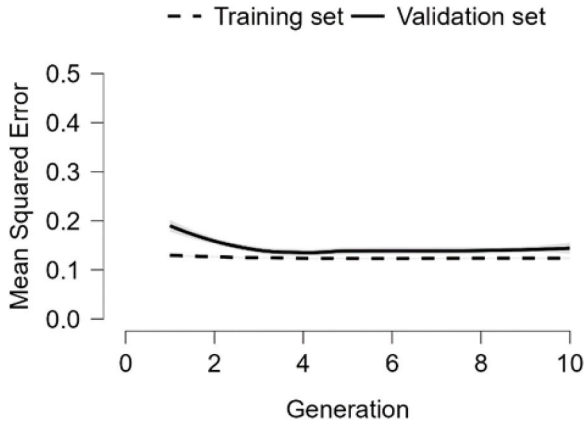

Fig. 3. Mean squared error plot.

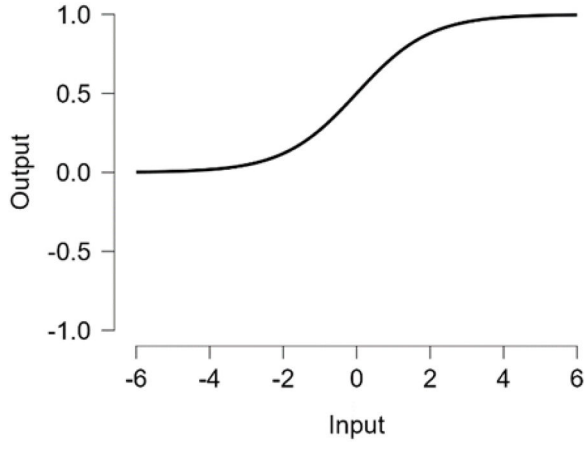

Fig. 4. Logistic sigmoid activation function.

physical and digital features in objects helps to improve consumer interactions. The paper investigates how consumer connection, innovation, personalization, and sustainable consumption influence the intentions of hybrid product patronage. These elements' mediating and moderating roles are investigated in this paper to help to understand customer behavior towards phygital products. The results reveal how engagement strategies can create long-term loyalty and support in a tech-driven, competitive company. Knowing these interactions enables companies to exceed customer expectations and grow sustainably in this challenging environment.

The first theory, that phygital product patronage intentions are much influenced by customer involvement, shows how vital engagement is in hybrid physical-digital product consumer behavior. Empirical data of great significance reveals that customer engagement boosts brand loyalty and repeat sales (Patil et al., 2024). Customers are likely to find a bond with the brand through interaction with it either cognitively, emotionally, or behaviorally. As it is based on physical and digital aspects, the usability, functionality, and experience of phygital goods rely on interaction. This interaction brings value to products and their satisfaction and, hence, repeat business. Phygital and physical and digital relations with the customer have typically increased an emotional relation with the firm (Sakas et al., 2024). This demonstrates that engaging consumers with a firm through phygital products may bring greater loyalty and repeat business since value and satisfaction are created. Firms that engage the consumer with phygital can expect more loyalty and repeat business since it creates value and satisfaction.

The second hypothesis was further supported: how consumer interaction impacts patronage intentions, personalization, innovation, and sustainable consumption. Sustainable consumption and personalization help in building consumer involvement and loyalty. According to Alesanco-Llorente et al. (2023), personalization increases the consumer's perceived value and relevance of a product, enhancing satisfaction and loyalty. Engagement values and searches for customized experiences raise consumer pleasure and brand loyalty. Sustainable consumption of phygital products influences consumer behavior and adheres to ethical and environmental standards. Engaged and environmentally conscious consumers value ethical brands and support the sustainable features of such brands (Pangarkar et al., 2022). They are indispensable because sustainability and personalization balance the intentions of patronage. Indeed, the personalization and sustainability of phygital products might improve consumer experiences, increasing loyalty when expectations change.

The third theory examines how consumers' behavior can influence the patronage intentions of phygital products and customer involvement. This theorizes that the customer's involvement and patronage are much influenced by behavior. The user attitude towards phygital objects can change the influences of engagement on loyalty and purchase intentions. Pangarkar et al. (2023) found that technologically comfortable and passionate consumers are more likely to interact with and value phygital objects, increasing patronage intentions. Non-tech-savvy customers may interact less; thus, involvement is the bridge to patronage in this context. This moderation elevates customer behavior and preferences for product interaction in the phygital world. Firms need awareness of how consumers behave and the change in engagement strategy to achieve the intended expectation and develop client loyalty. Engagement and loyalty in optimizing the phygital approach will amplify the growth and success rates of the brands.

According to the fourth hypothesis, consumer behavior is explained significantly by personalization and sustainable consumption mediating between customer interaction and phygital product patronage intention. This demonstrates how sustainability, innovation, personalization, and engagement build brand loyalty and consumption. Personalization customizes interactions to meet consumer demands, increasing customer involvement and product relevance. Customized experiences reportedly make consumers happy and more inclined to buy again Pangarkar and Shukla (2023). Personalization in phygital products ties digital and physical elements for a more exciting experience. These days, many consumers give ethics and the surroundings some thought (Yang & Garnier, 2022). Belief in a company's sustainability helps to increase consumer involvement and patronage. Phygital strategies must combine sustainability and customization to inspire customer loyalty since they interact with consumers.

Furthermore, the last theory was supported, which investigates how consumer behavior shapes the link between customer engagement and patronage intention for phygital products, enhancing our knowledge of

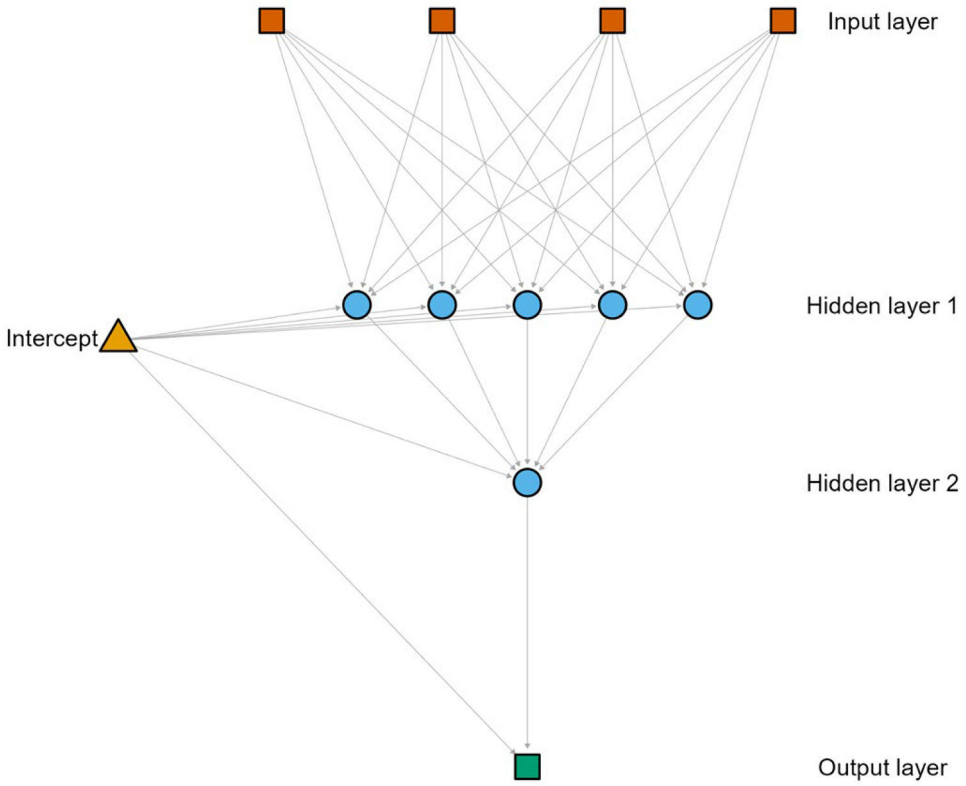

Fig. 5. Network structure plot.

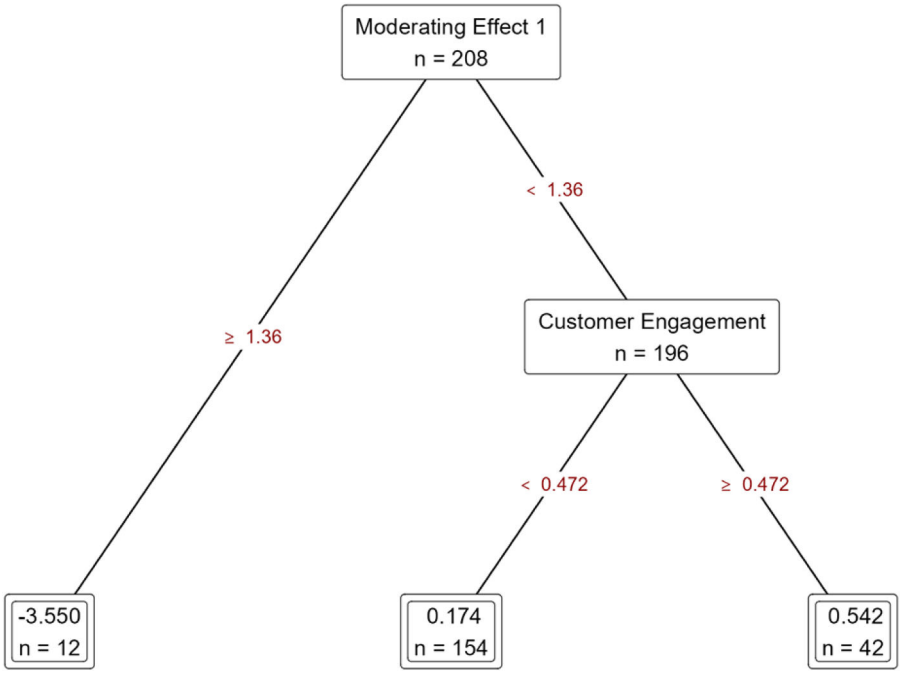

Fig. 6. Decision tree plot.

consumer interactions with these products. With various consumer categories responding differently depending on phygital product use, customer behavior significantly affects how engagement techniques affect patronage intentions. According to Brun (2023), engagement can be influenced by consumer sensitivity to hybrid items and digital technology. Digitally informed consumers interact more with phygital products, raising their buy inclinations. From consumers who are less at ease or interested in digital features, phygital products could lose appeal and loyalty. This moderation emphasizes the requirement of customizing interaction strategies to fit consumer behavior in order to attract every group and boost patronage.

These results are relevant for cross-border e-commerce marketplaces operating in phygital spaces worldwide. With these spaces only going further into expansion, multinational firms may use the findings from

this study to better design strategies for customer engagement, combining digital convenience with in-store personalization. The fact that the SEM-ANN model highlights the significance of adaptability in consumer engagement indicates its potential applicability in other markets with varying cultural norms and consumer expectations. An extensive investigation of the five hypotheses reveals the complex interplay of customer involvement, innovation, personalization, sustainable consumption, and phygital product consumer behavior. This theory underlines the need for a multifaceted consumer engagement strategy in which sustainability and customization control consumer expectations. Consumer behavior slows down. Hence, businesses have to adjust their strategy to tastes and habits. These results show that companies must include customers and provide customized and sustainable phygital solutions if they want long-term loyalty. Addressing these traits using more relevant and exciting consumer experiences helps brands prosper in a changing market. This research helps companies negotiate the phygital era and keep customers preparing for future studies and applications.

Conclusion

Customer engagement, innovation, personalization, sustainable consumption, and the moderating effects of consumer behavior influence consumers' decisions to buy phygital products. The neural network model describes customer intention components in complicated, nonlinear phygital situations. This study shows that phygital marketing is rising in retail, where physical and digital interactions are merging. Decision tree analysis directly predicts consumer behavior by revealing moderating factors and their relationship to customer involvement. Marketing practices should enable rational and sound choices by consumers in virtual and real-life conditions. This study contributes to developing phygital marketing theory and practice in Pakistan's growing e-commerce business. The findings can help companies and marketers enhance the strategies that attract the desired clientele and foster fervent patronage intentions. This study will strengthen further research by fusing classic marketing concepts with state-of-the-art analytical techniques while integrating theory and practice. The report calls for marketers to change consumer preferences and behaviors by changing technological advances. Results have implications for international firms conducting phygital marketing outside of Pakistan. Success and a favorable position over others will depend simply on a deep understanding of the engagement and loyalty of customers if the natural and digital worlds are blurred. This study not only contributes to the enrichment of the theory but also introduces novel methodologies, which would be suitable for elaborating this complex behavior of consumers—the integration of neural networks with decision tree analysis. The findings indicate personalization and sustainable practices that must be used to mold phygital consumer engagement, thus providing actionable insights for global e-commerce platforms. Hence, this study sets precedence for further investigations into hybrid consumer marketing while investigating ways to expand the applicability of SEM-ANN in phygital research.

Implications of the study

This research contributes to developing phygital marketing, customer behavior, and theory integrating digital-physical retail on different levels. This study applies SEM and ANN to examine the complex, nonlinear interactions between customer engagement, innovation, personalization, sustainable consumption, and patronage intentions. The results show that consumer behavior moderates these relationships, indicating that linear models may only partially capture how customers interact with phygital items. In this respect, combining psychological theories of involvement with modern analytical methods presents an essential gap in literature while also providing a more holistic approach to understanding consumer decisions. Decision tree analysis would provide a new methodological contribution to explain how specific segments of consumers react toward various phygital marketing methods. This research strengthens the theoretical framework of consumer behavior in phygital settings, and it challenges former models about innovation, personalization, and sustainability being essential drivers for consumer loyalty and engagement. The paper underlines that in developing countries like Pakistan, where the digital economy is rapidly evolving, such elements' dynamic interaction must be met. It leaves the following research capable of using these results as a foundation to advance on other customer concerns during more sophisticated retail experiences. This study's theoretical contributions are within existing consumer behavior models, emphasizing the importance of hybrid consumer experiences. It extends the comprehension of linear models of phygital marketing as it finds nonlinear connections between engagement, personalization, and sustainability, implying that consumer engagement is not static but dynamically affected in real time by a constellation of factors. This study, therefore, takes forward a theory of consumer behavior and emphasizes that the play of various dimensions is essential in hybrid marketing.

Significant implications of this study apply to phygital stores, e-commerce systems, and marketers. This study provides businesses with practical knowledge of how consumer involvement, customization, and sustainable consumption influence patronage intentions, helping increase client retention and satisfaction. The results highlight the requirement for tailored and environmentally friendly experiences that satisfy contemporary consumers' values and expectations for e-commerce sites like Daraz and Yayvo. The study segments consumers by participation and behavior using decision tree analysis, enabling companies to enhance their marketing initiatives. Businesses can target high-engagement consumers with tailored offers and environmentally conscious activities, influencing their purchases. The study also indicates that phygital product use is moderated by customer behavior, so companies should look at the usage of different consumer segments. Better focused marketing campaigns that satisfy the needs and preferences of various customer groups could follow from this, in which marketing efficacy is maximized. Advanced analytical techniques such as SEM-ANN allow companies to make data-driven decisions and better grasp the complex, nonlinear relationships of client behavior. This study strengthens customer ties and increases long-term growth in a competitive sector, guiding companies across the evolving phygital terrain.

Limitations and future research directions

This research has contributed significantly toward understanding consumer behavior in the phygital marketing phenomenon but needs to be improved. Firstly, the study is conducted in Pakistan, limiting its relevance to other countries due to cultural, economic, or technical environment differences. Daraz and Yayvo are such examples of famous sites in Pakistan, which need to reflect global experience with the phygital. Hence, the results of the current study would not have relevance in markets that operate under different consumer behaviors, different adoption rates of technology, and digital interaction. This study also makes use of the self-reported data of the customer. Data subject to biases from either social desirability or memory might also appear.

Even with existing studies, scales might be insufficient to capture the phygital experience and the type of consumer involvement. SEM-ANN and decision tree approaches remain robust lines of analytical inquiry because they offer fewer limitations in interpreting nonlinear interaction and handling complex model output. The ability of the study to rely heavily on the use of JASP 0.19.0.0 statistical software would present a limitation to its replication in other scenarios where different analytical techniques are used.

While this SEM-ANN usage is insightful, its complexity could be demanding to interpret by stakeholders with no background in advanced statistical methods. It may be possible to explore alternative models that are more interpretable or extend the longitudinal design to

better understand these emerging trends in phygital consumer behavior over time. Cross-regional studies comparing different cultural markets could be insightful for further grounding the scalability of engagement and personalization strategies in global phygital marketing.

These limitations call for future study that is both important and exciting. Broadening the research to include several geographical areas and customer groups will increase generalizability and offer a complete understanding of phygital marketing in many economic and cultural settings. Future studies might examine how AR and VR enhance consumer involvement, patronage intentions, and phygital experiences. Longitudinal studies help prove how phygital consumer behavior changes with time in reaction to fast technology development and the evolution of consumer preferences. In addition to the numerate results, qualitative methods such as in-depth interviews or focus groups can provide more context-specific insights. Future research may include aspects of how the application of the phygital marketing tool relates to consumer trust, perceived value, and brand loyalty, amongst other elements, in creating the complete picture of digital consumer behavior. Companies must consider ethical data use and customization issues in phygital marketing to include customers and maintain transparency and trust. Such future directions may advance academic knowledge and valuable applications in phygital marketing, a field of constantly expanding relevance.

CRediT authorship contribution statement

Rana Salman Anwar: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Rizwan Raheem Ahmed:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Formal analysis. **Dalia Streimikiene:** Writing – review & editing, Project administration, Data curation, Conceptualization. **Wadim Strielkowski:** Visualization, Validation, Software, Project administration, Funding acquisition. **Justas Streimikis:** Writing – review & editing, Visualization, Validation, Supervision, Software, Methodology.

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