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Exploring the impact of affordances on consumers' adoption

Robotic vacuum cleaners case study

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Abstract

The rapid advancement of technology has resulted in the proliferation of a wide array of digital products and services, which differ from traditional artefacts by incorporating digital components.

The evolution of the nature of artefacts has several implications for the design process. One crucial aspect to consider is related to the impact that such evolution has on the artefacts' associated affordances. The term "affordance," introduced in the 1970s by Gibson, has generated ambiguity and confusion in academic discourse over the years. This term denotes the potential actions that an artefact enables or facilitates for its users.

The concept of affordance is closely connected to interaction, and at the same time, examining how users interact with digital products and services is essential for achieving success in a competitive market. As such, both concepts should be considered when developing acceptance and adoption models. Such models are theoretical frameworks designed to understand and explain the key factors influencing the adoption and use of new technologies. Over the years, various models have been proposed, including the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), the Value-based Adoption Model (VAM), and the Innovation Diffusion Theory (IDT). These models aid researchers in better comprehending users' needs and behaviours, leading to the successful implementation and widespread acceptance and usage of new technologies.

The present thesis combines the concepts of affordance and adoption of an artefact. It begins with a literature review on the two concepts of "artefact" and "affordance", then examines technology diffusion and adoption theories to identify influential factors in the adoption decision. It also explores the impact of affordances on the acceptance of new technologies. Based on previous studies, six major affordances are proposed to significantly influence users' acceptance: cognitive affordance, physical affordance, functional affordance, sensory affordance and emotional affordance. Drawing from the Technology Acceptance Model (TAM) and prior research, a comprehensive affordance model is developed, along with a proposal for a questionnaire based on the case study of the digital evolution of vacuum cleaners into robotic ones.

This research can serve as a foundation for future studies aimed at improving smart products by enhancing the users' experience and gaining a deeper understanding of customers' needs.

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Chapter 1

INTRODUCTION

1. The Problem

The digital era has brought in an abundance of digital artefacts, encompassing both products and services with integral digital components. Understanding the intricate factors that influence customers' acceptance and adoption of these technologies is pivotal in today's competitive landscape. Over the years, several theoretical models have been developed to delve into these dynamics, such as the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), the Value-based Adoption Model (VAM), and the Innovation Diffusion Theory (IDT). Each model offers unique perspectives on the drivers and barriers affecting adoption.

Building upon these foundational frameworks, scholars have expanded the discussion by introducing additional variables that play crucial roles in shaping adoption behaviours. One such concept is affordance, as articulated by Norman (1988), which refers to both the perceived and actual properties of an object that dictate its potential uses. Affordance thus becomes a significant factor to consider when examining how users interact with and adopt new technologies.

Among these models, the Technology Acceptance Model, pioneered by Davis in 1989, remains the most widely applied framework for studying user acceptance. It posits that perceived ease of use and perceived usefulness are central determinants of an individual's intention to use a specific technology. Within this framework, affordance could be studied as an external variable that influences users' perceptions and behaviours.

As digital artefacts continue to proliferate, understanding the interplay of the factors affecting technology adoption becomes increasingly complex and essential. Integrating concepts like affordance into established models enhances the ability to predict and explain adoption patterns, thereby outlining strategies for designing and introducing new digital innovations effectively.

2. The Aim of the Work

The aim of this research is twofold: firstly, to provide clarity on the concepts of artefacts and affordance in the context of the digital transition; and secondly, to conduct a comprehensive review of existing theories on technology diffusion and adoption. By synthesizing these theories, the study underlines the critical factors that drive adoption decisions across various contexts and demographics.

Furthermore, the research endeavours to delve into how affordances, as defined by Norman (1988) as "the perceived and actual properties of an object that determine its potential uses", influence the acceptance of emerging technologies. This exploration will contribute to a deeper understanding of how users perceive and interact with new technological innovations.

The work explores affordances as categorized by Hartson into cognitive, physical, functional, and sensory dimensions and the concept of emotional affordances as external factors within the Technology Acceptance Model framework developed by Davis (1989). A questionnaire has been developed to assess these variables within a population sample.

3. The Methodology

The study uses a case study approach to analyse the willingness of users to switch from traditional vacuum cleaners to robotic vacuum cleaners. This methodology facilitates a detailed examination of how the different affordances impact users' perceptions and acceptance of the new technology of robotic vacuum cleaners.

A structured questionnaire is crafted with specific ad-hoc questions tailored to the nuances of this case study. It aims to capture insights into how each type of affordance impacts users' perceptions and interactions with robotic vacuum cleaners. Additionally, the questionnaire integrates the key variables from the Technology Acceptance Model (TAM): perceived ease of use, perceived usefulness, attitude toward use, and intention to use. These variables are essential for understanding the factors that drive the adoption and acceptance of technological innovations.

4. The Structure of the Document

The document, following this introductory chapter that sets the framework, is structured as follows:

- *Chapter 2* aims to provide a comprehensive understanding of artefacts by defining and classifying them, with a focus on digital artefacts. It also explores the concept of affordance, reviewing relevant literature to elucidate its significance in interaction design.

- *Chapter 3* presents a literature review of influential theories on technology diffusion and adoption. This includes a critical examination of the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), the Value-based Adoption Model (VAM), and the Innovation Diffusion Theory (IDT), highlighting their respective contributions to understanding adoption processes.

- *Chapter 4* introduces the selected case study and contextualizes such innovation. It proposes an extended TAM model that incorporates affordances as external variables influencing technology acceptance. To validate this model, the study outlines a questionnaire designed specifically for the case study focusing on robotic vacuum cleaner affordances.

- *Chapter 5* concludes the document, summarizing the key findings and the insights drawn from the study. It synthesizes the implications of the research and suggests avenues for future research to further refine and validate the proposed extended TAM model.

Chapter 2

ARTEFACT AND AFFORDANCE

Over the last two decades, digitalisation has emerged as the primary source of innovation with more digital innovations occurring than physical ones. This shift has brought about changes in the design process of both digital and physical artefacts (Cantamessa et al. 2020). Among the changes in the design process, this thesis focuses on the concept of affordance as the behaviour and interaction of users with an artefact are significantly influenced by its nature (D. Norman 1988). Designers indeed must consider the interactions between the user and the artefact during the design process (D. Norman and Draper 1986). For a product to be easy to use, it needs to match the user's physical characteristics and allow its functions and potential dangers to be easily noticed without much thinking. Designers should concentrate on providing a variety of visible support features that are easy to understand (Seet and Goh 2012).

1. Understanding Artefacts

Digitalisation has driven the shift from non-digital to digital artefacts. Recently, there has been a noticeable trend toward transitioning from product-based to service-based offerings, a shift often enabled by digitalisation.

These transitions have resulted in the creation of a vast array of artefacts, which in general, aim to reduce human involvement (Altshuller 1999) by introducing automated or service agents. Each artefact has its specific design process and distinct characteristics that significantly impact the user's interaction (D. Norman 1988).

To understand how the design process of artefacts changes with digitalisation it is crucial to establish a precise definition of artefacts. The term "artefact" is defined in the vocabulary as:

- An object made by a human being, typically one of cultural or historical interest (Oxford Dictionary).

- Something observed in a scientific investigation or experiment that is not naturally present but occurs as a result of the preparation of investigative procedure (Oxford Dictionary).

The definitions provided are broad and may not encompass all aspects of the term. To this end, Tiotto (2022) in her thesis work proposed a more detailed definition of artefacts.

1.1 Artefact Classification

Starting from an extensive review of product and service concepts, Tiotto (2022) proposed the categorization of artefacts into six distinct classes. These categories have been defined as follows (Tiotto 2022):

- *Non-digital products*: A non-digital product is a purely material object designed to anticipate and meet users' needs (Kotler et al. 2007). The product results from a standardized production process that occurs before its consumption and ensures homogeneity in both quality and performance. The product's physical nature allows it to be conveniently stocked and traded in the market (Hill 1977; Zeithaml 1981).

- *Non-digital PSS (Product Service System)*: A non-digital product can be used to provide a service. The physical component of the product is the output of a standardized process and can be stored. In contrast, the service is bespoke and tailored to the requirements of the individual user and is rendered simultaneously with its consumption. This service can be sold and traded in the market but cannot be stored for future use (Goedkoop 1999; Ana Valencia et al. 2015).

- *Non-digital service*: It is an intangible performance able to satisfy and anticipate users' needs (Zeithaml 1981). It is the outcome of a unique and customized process that gives it heterogeneity in both performance and quality perspectives. It contemplates an interaction with the user and the simultaneity of consumption. Since it does not use any physical or digital device to be dispensed it cannot be stocked but it can be sold and provided (Jackson, Neidell, and Lunsford 1995; Hill 1977; Lovelock and Gummesson 2004).

- *Digital product*: A material object that aims to anticipate and satisfy users' needs. Due to its intangible component, it also stores and transfers information. It has a dual function: to satisfy or anticipate users' needs and to allow the exchange of information. Only the non-digital module is the outcome of a standardized production process that occurs before the consumption of the product itself. The digital component can be copied, recombined and modified over time. Digital products are experience goods that interact with other objects, humans and the surrounding environment. It can be stocked and traded in the market (Rayna 2008; Vitali, Arquilla, and Tolino 2017).

- *Digital PSS (Product Service System)*: A digital product that provides intangible services through a physical device. The physical components are standardized and can be stocked, while the service is unique and customized, provided simultaneously with consumption. The service can be sold and traded in the market but cannot be stored (Baheti and Gill 2011; E. Lee 2015).

- *Digital service*: They are intangible performances that are not provided through a physical device. They aim to satisfy and anticipate user needs and transfer information. They are the result of a unique and customized process that happens simultaneously with consumption. Digital services are experience goods that can interact with the user, the environment, and other digital devices, enabling the storage and transmission of information. (Rayna 2008; Vitali, Arquilla, and Tolino 2017).

In recent years another construct has been introduced, the concept of Cyber-Physical System. CPSs are a new generation of systems capable of expanding the abilities of the physical world towards computation, communication and control (Baheti and Gill 2011). They are systems connecting the physical and digital worlds (E. Lee 2015).

The proposed artefacts classification can be represented graphically through a Cartesian diagram as reported in Figure 1.A. The graph is conveniently divided into four quadrants, each of which is defined by the intersection of two axes. The abscissa axis illustrates the transition from product to service, while the ordinate axis depicts the shift from non-digital to digital. Therefore, the graph effectively categorizes the transition of businesses from tangible product offerings to intangible services, and from traditional non-digital mediums to modern digital platforms. In Figure 1.B different types of artefacts are represented in space and colour based on their features. Digital and service transition are represented by yellow and blue shades, respectively. It's important to note that the two dimensions should

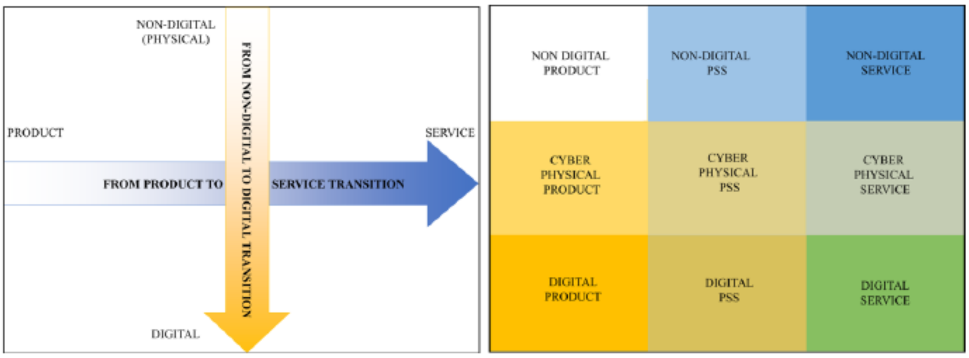

FIGURE 1: A) SERVICE AND DIGITAL TRANSITION; B) ARTEFACTS CLASSIFICATION

not be interpreted strictly as Cartesian axes (Monti et al. 2024). For example, a Cyber-Physical Product combines physical and digital aspects, while a PSS (Product-Service System) combines features of both products and services. In other words, PSSs don't necessarily represent artefacts with reduced tangible aspects; they can be just as tangible as a product, but with an additional non-tangible service component.

1.2 Digital Artefact Characteristics

Digital artefacts, as defined by Tiotto (2022), serve the purpose of meeting or anticipating customers' needs and are a combination of an intangible component (bitstring) and a material one (means or bearer). They can be stored and used for storing, transmitting, and transferring the information contained in the intangible part.

Digital artefacts have a unique nature that gives them the following characteristics: non-rivalry in consumption, non-excludability, durability over time, ability to be copied without high cost or effort, multifunctionality, and recombinability (Rayna 2008; Quah 2003). They represent an 'experience-good' that can interact with other objects, humans, or the surrounding environment (Vitali, Arquilla, and Tolino 2017). Digital artefacts often facilitate the use of technology-based services, serving as the interface for these services (also referred to as 'service access equipment'; (Sandström et al. 2008)).

Digital artefacts differ from physical ones. Eck (2015) highlighted four main fundamental characteristics of digital artefacts:

- *Editability* pertains to the ability to consistently and methodically modify or update an artefact while retaining its logical structure. This can be accomplished by rearranging the elements comprising a digital object, removing existing elements, adding new ones, or adjusting the functions of individual elements. In some instances, it is inherent in the object through regular or continuous content or item updates.

- *Interactivity* refers to the ability to explore a digital artefact, including its components and dependencies, and to follow different pathways to activate embedded functions or explore the arrangement of information items. Unlike editability, interactivity does not result in any modifications to the digital object.

- *Reprogrammability* allows to separation of the digital artefact from its context of use, modify its structure, and reuse it for other purposes.

- *Distributedness* means that the digital artefacts are not contained within a single source or institution, but they are distributed.

Along with these characteristics, Eck (2015) proposed also three technical attributes:

- *Modularity* refers to the quality of digital artefacts allowing for independence and not being bound to a fixed product architecture. Individual modules of a complex digital artefact can be transferred to completely unrelated use contexts.

- *Granularity* refers to the ability to break down digital artefacts into their smallest components and to modify a part of the artefact at various levels of abstraction, whether a small or significant part. While modularity deals with the connections between blocks, granularity focuses on the individual parts that make up these blocks.

- *Reflexive dynamics* mean that any access, assembly, or manipulation can only be performed through the use of other digital artefacts. Consequently, any domain with digital artefacts will see an increase in digital artefacts over time.

1.3 Layered Modular Architecture

Digital artefacts exhibit a layered modular architecture, a structure characterized by its dynamic and flexible nature (Kallinikos, Aaltonen, and Marton 2010; Yoo, Henfridsson, and Lyytinen 2010). This flexibility is enabled by features such as interactivity, editability, re-programmability, distribution, and technical attributes like modularity, granularity, and reflexive dynamics.

In contrast, physical products with a modular architecture have components and functional sub-assemblies specifically designed for a particular product, ensuring each part fits and operates within that specific design framework (Ulrich 1995). However, a layered modular architecture in digital artefacts allows for product-agnostic components. These components can be integrated seamlessly without concerns over interface dimensions or specific design requirements. Unlike traditional modular systems where components belong to the same design hierarchy, components in a layered modular architecture are independent of such constraints, promoting greater flexibility and autonomy in their development and integration (Clark 1985).

A digital artefact utilizing a layered modular architecture can continually evolve. This evolution is facilitated by the ability to recombine and reconfigure components, enabling ongoing improvements and adaptations without necessitating a complete redesign.

The layered modular architecture of digital artefacts significantly shapes user interactions by offering scalability, customisation, and seamless integration with other systems. This architecture supports efficient upgrades, ensuring that interactions remain consistent and adaptable to evolving user needs. By tailoring user-artefact interactions to individual preferences, usability is enhanced and robust functionality is provided, thereby ensuring an overall user-friendly experience.

2. The Concept of Affordance and its Evaluation

User behaviour and interaction with an artefact are profoundly shaped by its inherent characteristics (D. Norman 1988). Designers must carefully consider these interactions throughout the design process (D. Norman and Draper 1986). Affordance, which describes the perceived actions an object suggests to a user, is pivotal in design practice. It directly influences usability, learnability, and overall user satisfaction with the artefact.

Evaluating affordance involves assessing how well these perceived actions align with the interactions intended by the designers. Key factors in this assessment include the clarity of design cues, the intuitiveness of interactions, and the alignment between user expectations and actual functionality. Understanding and optimising affordance thus play a critical role in crafting intuitive, user-centred designs that enhance usability and user experience.

2.1 Affordance Definition

The concept of “affordance” is considered essential for the design activity (Maier and Fadel 2009). The designers should focus on the human ability to understand an artefact instead of designing the artefact first and expecting the human to understand the machine’s logical behaviour (D. A. Norman 2013). A user, to be able to operate a product, must be able to perceive the possible actions, the so-called affordances.

The term “affordance” was coined for the first time by J. Gibson in Ecological Psychology (1977) to explain how animals without incurring any type of reasoning can grasp the intrinsic meaning of an object using only sensorial perception (Gibson 1977). The affordance perceived by the animal is enabled by some physical features of the environment such as size, surface and material. In summary, for Gibson, affordance represents the perception, originated by the senses, that the user has of the relationship established between him and an object within an environment.

Affordances exist independently from the observers’ perception and can be positive or negative, depending on whether they are beneficial or injurious for the observers (Gibson 1977). Actors perceive the various types of affordances that the environment provides, and based on these affordances, they determine their actions in the environment. In other words, an affordance is a potential feature of objects that allows actors to use objects in any way in the environment.

According to Gibson and the field of Ecological Psychology that emerged from his work, the objective of design is to facilitate direct perception by providing sensory information, thereby reducing the mental burden associated with perceiving affordances for the user (Masoudi et al. 2019).

Norman applied the concept of affordance to the Engineering Design field. In his work, The Psychology of Everyday Things (D. Norman 1988), he describes how affordances are the result of the object interpretation based on experience and knowledge that the actor applies to perceive the object. Norman’s use of the concept is fundamentally different from its original use, for him it is an internal mental process linked to the user’s interpretation of the artefact through knowledge and previous experience.

Norman (1988) decomposed the affordance concept into real and perceived affordances. Real affordances refer to the physical characteristics of an object that facilitate user actions, while perceived affordances provide external clues that help users recognize an object and determine its potential actions. Norman emphasized the importance of perceived affordances in design and introduced some principles to enable users to complete tasks easily and simply.

He highlighted the necessity of conveying information through clear and concise text to enhance system usability and emphasized minimizing unnecessary information and choices for a streamlined design. Norman also advocated for providing feedback to help users recognize their progress and the results of their actions. Designing icons and graphics as metaphors was recommended to predict the method and outcome of operations. Furthermore, he stressed the importance of incorporating constraints to prevent user errors. Additionally, he advised including error messages and "undo" functions to help users recover from mistakes and designing the system to enable problem-solving based on previously acquired information.

According to McGrenere and Ho (2000), a key difference between Ecological Psychology and Norman's approaches to affordance is their view of perception. In the Ecological approach, affordances are seen as independent of the animals' perception, while Norman's view acknowledges that perception can play a role in the presence of an affordance (Mcgrenere and Ho 2000). Therefore, Norman's perspective significantly diverges from the Ecological view of direct perception.

Various scholars have proposed different interpretations of affordance to help researchers explain the variability in perceptions related to contextual information. However, this diversity of interpretations has unfortunately led to confusion within the literature. Two primary interpretations of affordance can be identified:

- *Sensory affordances* arise from the sensory perception of the artefact and lead the user to interact by triggering action through evoking past memories. These affordances become evident to the user before any action is taken (Perpignano 2020).

- *Experiential affordances* emerge only after the user has taken action and are linked to perceptions about the use of the artefact. They influence the user's experience and affect their inclination to use the artefact again (Pucillo and Cascini 2014).

Since Gibson's work (Gibson 1977), a plethora of studies have aimed to define, clarify, and apply the concept of affordances across various disciplines that explore interactions between humans and objects in the environment. However, there remains a high level of ambiguity surrounding the concept due to the multiple definitions constructed over time without standardized criteria to ensure robustness (Evans et al. 2017). Evans (2017) highlights this ambiguity within the literature and identifies three primary factors contributing to the confusion:

- Different studies analyse and discuss the same concepts using entirely different terminology.

- Many authors offer lists or classifications of affordances without pausing to define each affordance individually.

- The term "affordance" is used in contexts where its commonly accepted definition does not apply.

2.2 Emotional Affordance

The concept of affordance, originally developed by Gibson (1977), has been extended to include emotional affordances by Morie et al. (2005). Affordances are not limited to physical actions; they also encompass emotional responses that users may experience within an environment. Emotional affordances refer to environmental elements that prompt emotional reactions and enable emotional experiences (Bareither 2019).

Social interactions involve dynamic inter-body communications. Jensen (2016) emphasises that emotions are perceived and expressed through whole-body movements, including facial expressions, gestures, vocalizations, and postures. This interplay allows for phenomena like emotion contagion, where one person's emotions influence another's emotional state (Hatfield, Cacioppo, and Rapson 1993), illustrating the relational aspect of emotional affordances.

Affordances, as relational phenomena (Chemero 2003), depend on both the properties of the technology and the characteristics of the interacting agent. These include cognitive and bodily attributes, cultural knowledge, and social norms (Hammond 2010). For example, the meaning of an outstretched hand as a greeting gesture varies across cultures, illustrating how cultural norms influence affordances.

Because emotional affordances are shaped by individual and cultural factors, there is a diversity in how different social groups perceive and respond to them. This diversity highlights the variability in emotional affordances across contexts and individuals.

Emotional affordances can lead to various emotional outcomes, positive or negative, intended or unintended, and are crucial in designing experiences that induce optimal flow states (Kyttä 2003).

Steiner and Dennis (2022) define emotional affordances as the relational properties of technology that evoke emotional states or behaviours, such as expressing or reacting to emotions. Carter et al. (2016) define emotional affordances as "all the mechanisms that have emotional content as a way to transmit and collect emotional meaning about any context; it can include bodily expressions, social norms, values-laden objects, extended spaces, …".

Norman (2004) underscores the pivotal role of emotions and affordances in design, particularly in human-technology interactions (T. Park and Lim 2018). Emotional affordances have been applied in enhancing human-robot interactions (Vallverdu and Trovato 2016), shaping social media technologies (Steinert and Dennis 2022), and developing emotionally supportive online learning environments (T. Park and Lim 2018).

Norman (2004) proposed a user-centred approach integrating emotions in design, focusing on three levels: visceral, behavioural, and reflective.

The Visceral Level

At the most fundamental level of processing lies the visceral response. This innate reaction is universal among humans, enabling rapid judgments about the environment, whether it is favourable or threatening, without conscious awareness or control.

Visceral learning primarily occurs through sensitisation or desensitisation, influenced by mechanisms like adaptation and classical conditioning. These responses are swift and automatic, triggering reflexes such as the startle response to unexpected stimuli. They also encompass genetically programmed behaviours like fear of heights, aversion to darkness or loud noises, distaste for bitterness, and preference for sweetness. Visceral responses operate swiftly and subconsciously, solely attuned to immediate circumstances.

In design, understanding visceral responses hinges on immediate sensory perception: the soothing resonance of a melodic tune versus the grating scrape of fingernails on a rough surface. This domain concerns aesthetics, how something looks, sounds, feels, or smells, eliciting instinctive attraction or aversion. It is distinct from considerations of usability, effectiveness, or comprehension. Exceptional designers harness their aesthetic sensibilities to evoke specific visceral reactions.

Engineers and other analytical minds often disregard visceral responses as inconsequential. They take pride in the technical excellence of their work and are puzzled when inferior products outsell theirs purely based on appearance. Yet even these logical thinkers make subconscious judgments, evident in their preferences for certain tools over others. Thus, visceral responses are significant in shaping perceptions and preferences across all individuals.

The Behavioural Level

The behavioural level encompasses learned skills, activated by situations that match established patterns. Actions and analyses at this level occur largely subconsciously. When performing a well-learned action, we only need to focus on the goal; the behavioural level manages the details, leaving the conscious mind free from involvement beyond initiating the desire to act.

For designers, the critical aspect of the behavioural level is the association between actions and expectations. Anticipating a positive outcome results in a positive emotional response. Conversely, expecting a negative outcome leads to a negative emotional response, manifesting as dread, hope, anxiety, or anticipation. The feedback loop of evaluation plays a crucial role in confirming or disconfirming these expectations, leading to satisfaction, or disappointment and frustration.

Behavioural states are learned, raising a sense of control when there is a clear understanding and awareness of results. Conversely, frustration and anger arise when things do not go as planned, especially when the reasons or possible remedies are unknown. Feedback provides reassurance, even when it indicates a negative result. A lack of feedback creates a feeling of being out of control, which can be unsettling. Thus, feedback is essential for managing expectations, and good design ensures its presence. Feedback is vital for resolving expectations and is critical for learning and developing skilled behaviour.

The Reflective Level

The reflective level is the realm of conscious cognition, where deep understanding, reasoning, and decision-making occur. Unlike the rapid, subconscious responses of the visceral and behavioural levels, reflection is slow and cognitive, typically taking place after events have unfolded.

Reflection involves looking back at events, evaluating circumstances, actions, and outcomes, and often assessing blame or responsibility. The most profound emotions arise from the reflective level, as it is here that we assign causes and make predictions.

The reflective level is the most critical of the processing levels for a designer. Reflection involves conscious thought, and the emotions it triggers, like guilt, blame, praise, and pride, tend to be the most long-lasting. Reflective responses become embedded in our memory of events, lasting much longer than the immediate experiences or the period of usage, which are influenced by visceral and behavioural levels. It is the reflection that drives us to recommend a product or to advise others to avoid it.

All three levels of processing (visceral, behavioural, and reflective) work together to shape a person's liking or disliking of a product or service. A single negative experience can taint all future interactions, while one outstanding experience can redeem past shortcomings. The behavioural level, which involves interaction, is also where expectation-based emotions like hope, joy, frustration, and anger arise. Understanding combines the behavioural and reflective levels, while enjoyment requires the integration of all three. Designing with consideration of all three levels is crucial.

While most products do not incite fear, poorly designed devices can cause frustration, anger, helplessness, despair, and even hatred. Well-designed devices, on the other hand, can induce pride, enjoyment, control, pleasure, and even love and attachment.

Ultimately, all three levels of processing collaborate to determine a person’s cognitive and emotional state. High-level reflective cognition can trigger lower-level emotions, and lower-level emotions can prompt higher-level reflective cognition.

Design Variables for the Levels of Emotional Affordances

Building on Norman's (2004) work on incorporating emotion into the design process, several studies have explored the design variables of various artefacts across the three levels of emotional affordance: visceral, behavioural, and reflective (T. Park and Lim 2018).

According to Desmet (2002), the visceral level pertains to the object's appeal to the user's attitudes, the behavioural level focuses on how the product meets the user's standards, and the reflective level considers whether the product helps the user achieve their goals.

Jordan (2002) and Tiger (1992) describe the visceral level as involving hedonistic benefits, which encompass sensory and aesthetic pleasures. The behavioural level addresses practical benefits, arising from task completion, while the reflective level involves emotional benefits, affecting users' emotions.

Van Gorp and Adams (2012) categorize the visceral level as relating to aesthetics, how the product looks and feels. The behavioural level involves the interaction between the user and the product, and the reflective level focuses on the product's function, and what it does.

Sanders (1992) emphasizes desirability at the visceral level, highlighting aesthetic appeal. At the behavioural level, the focus is on usability, so on how easily the user understands, learns, and utilizes the product. The reflective level concerns the product's usefulness and how well it accomplishes its intended purpose.

2.3 Affordance in Human-Computer Interaction

In 1991, Gaver applied the concept of affordance to human-computer interaction, defining affordances as "the properties of the world that enable some actions to an organism equipped to act in certain ways" (Gaver 1991; 1992).

The attributes of an object must convey information that the actor can perceive. Animals deduce a "compatible configuration" between the characteristics of an object and their capabilities, which shapes their way of acting. Thus, affordances must be perceivable, but they exist independently of perception. They are present whether or not they are perceived by the user. Designers should design effectively perceived affordances and uncover hidden affordances by implementing artefacts that transform the hidden affordances into real ones (Gaver 1991).

Gaver (1991) proposed a classification of affordances based on the information perceived by the user:

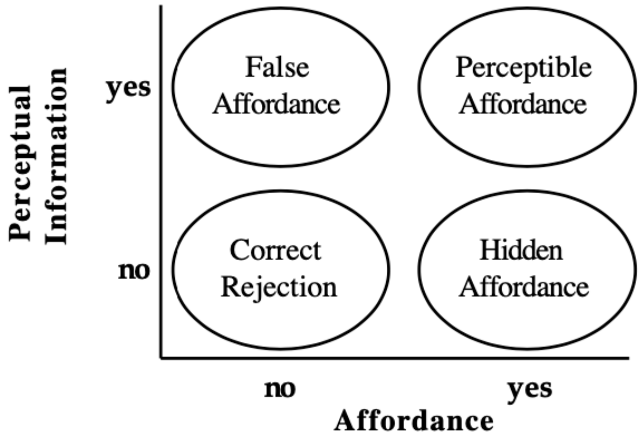

FIGURE 2: GAVER'S AFFORDANCE CLASSIFICATION

- *False affordance*: Information suggests a non-existent affordance, generating unintended stimuli for the user, which the designers did not intend.

- *Correct rejection*: No misleading stimuli are generated, ensuring the user is not tricked. There is no affordance, and consequently, no perceptual information is present.

- *Hidden affordance*: The user is unable to perceive the information needed to recognize the affordance, thus failing to experience the intended stimuli.

- *Perceptible affordance*: Information is readily available to the user, allowing them to perceive and interact with the affordance as designed.

This classification underlines the importance of information that allows the identification and perception of affordances.

After Gaver's study, other scholars worked on applying the concept of affordance in HCI. Hartson decomposed the affordance concept into cognitive, physical, functional, and sensory so that the affordance concept could be more effectively applied to interaction design (Hartson 2003).

Cognitive affordances, analogous to Norman's perceived affordances, refer to design features that help users recognize and understand objects or functions. Physical affordances, defined by Norman's concept of real affordances, involve design elements that facilitate users' physical interactions with objects or systems. Functional affordances include design features that enable users to accomplish tasks efficiently within a system, enhancing its functional utility. Finally, sensory affordances consist of design characteristics that aid users in perceiving and interacting with their environment, thereby supporting both cognitive and physical affordances.

Hartson (2003) emphasises the role of affordances in design and asserts that affordances facilitate the user's perception, understanding, and use of something (Cho and Choi 2020).

2.4 Evaluation of Affordances

According to Pucillo and Cascini (2014), usability can be used as a measure of a system's affordance. Given the abstract nature of the affordance concept, it can be challenging to study directly. Building on the work of (Chen et al. 2015), they proposed evaluating affordance through specific "affordance indicators".

Usability, as defined by ISO 9241-11, encompasses the Efficiency, Effectiveness, and Satisfaction with which a specific user achieves certain goals in a given environment:

- *Efficiency* is the level of resources (such as money, effort, or time) used to achieve the objective (Bevan and Macleod 1994).

- *Effectiveness* is the extent to which an objective is achieved defined in terms of accuracy, completeness and appropriateness (Bevan and Macleod 1994).

- *Satisfaction* is the measure expressing the user's appreciation of the system (Bevan and Macleod 1994).

Designers often strive to create products that are easy to learn and use. However, the outcome may not always be as usable as intended. Therefore, designers must be well-versed in usability principles and incorporate them into the design process for new products (Masoudi et al. 2019).

Using usability to assess affordance offers an approximate solution to the challenge of objectively measuring affordance. Currently, the literature lacks a quantitative method for objectively evaluating affordance. Nonetheless, it is suggested to utilize usability as a means of affordance evaluation (Mcgrenere and Ho 2000).

2.5 Digital Affordance

Digitalisation has significantly increased the complexity of artefacts, further complicating the design process due to the integration of digital technologies into products (Cantamessa et al. 2020; Jung and Stolterman 2011). This complexity poses a challenge in addressing "design affordance" for features and functionalities of digital products, also known as the problem of digital affordance (Oxman 2006; Yoo et al. 2012). This is because the interactions between the user and the artefacts cannot be considered independent of the nature of the artefact itself (J. L. Davis and Chouinard 2016).

Digital artefacts, due to their layered modular architecture (Yoo, Henfridsson, and Lyytinen 2010), are characterized by internal hierarchies of functional elements. This structure allows for multiple affordances to arise, leading to the conceptualization of nested affordances, a cluster of affordances which can be hierarchically defined.

This hierarchy of affordances can be divided into sensory and experimental affordances. As previously defined, sensory affordances arise from the sensory perception of the artefact and lead the user to interact by triggering action through evoking memories, while *experiential affordances* emerge only after the user has acted and are linked to perceptions about the use of the artefact. Considering that digital artefacts comprehend both products and services, it is better to associate the affordance categories with the different components of the artefact. Sensory affordances are related to the material component of the artefact, while experimental affordances are related to the immaterial one (Tiotto 2022).

Starting from the works of Evans et al. (2017) and Leonardi (2013), the concept of digital affordance is defined in the work of Perpignano (2020) and further analysed by Sanna (2022).

Digital Affordance is a "hierarchy of affordances that arises from the flexible nature of the design constraints of the digital artefact, determined by the set of relationships existing between the affordances themselves. It must be goal-oriented, its perception can be sensory and/or experiential and depends on the information context as well as on the relationships between the affordances themselves"(Colombo et al. 2022; Sanna 2022).

Evans (2017) suggested a methodology to support the design of digital artefacts and some adoptable criteria for the construction of the digital affordance concept.

- *Criteria 1*: confirm that proposed affordance is neither the object nor a feature of the object. Affordance is not only the relationship between the person and the object but also the relationship between the individual and his perception of the object in the environment (Parchoma 2014).

- *Criteria 2*: confirm the proposed affordance is not an outcome.

- *Criteria 3*: confirm the proposed affordance has variability. Affordances' variability is evident in several empirical works, demonstrating how contradictory behaviours of individuals using the same features lead to the achievement of different outcomes.

2.6 Evaluation of Digital Affordance

To address the challenge of evaluating the affordance of a digital artefact, Perpignano (2020) developed a comprehensive model building on the initial work of Roskos (2017). This model begins with a general analysis, followed by a structured evaluation and validation process aimed at identifying affordances and their elements within the context of user interactions. The process is composed of the following steps:

1. *Identification of the actors*: outlining their profile, objectives and interactions with the artefacts.

2. *Flowchart modelling*: use flowcharts (e.g. UML) to model the progression of user actions.

3. *Definition of digital system architecture*: use block diagrams to depict the system's modules and their elements, analyse the information workflow, and illustrate how the system functions and how various modules interact. This representation also highlights the hierarchy among modules and elements, indicating the hierarchy of affordances.

4. *Identification of the affordance indicators*: identify and group affordance indicators into categories such as Functionality, Communication, Content, Accessibility, Administration, and Tools (Roskos, Brueck, and Lenhart 2017).

5. *Identification of the affordances*: Identify affordances based on the system's functional structure, expressed through their relationships (Evans et al. 2017; Maier and Fadel 2009), in line with established methodologies and criteria in the literature (Evans et al. 2017; Chen et al. 2015).

6. *Construction of the incidence matrix*: create an incidence matrix that maps interactions between indicators (columns) and affordances (rows), allowing each affordance indicator to be associated with its corresponding affordance.

7. *Evaluation of the affordance*: evaluate affordances using the Guttman scale (Guttman 1944): +1 for positive perception, 0 for neutral or no evaluation, and -1 for negative perception.

8. *Final affordance assessment*: Use the incidence matrix and the evaluation of affordance indicators to identify negatively perceived affordances and understand which aspects of the system they impact. This assessment helps determine whether sensory or experiential perception prevails, guiding designers on which components of the digital system need intervention.

3. Affordance Factors

Hartson's types of affordances (2003) can be applied to enhance the ease of manipulating smart devices and obtaining desired services, thereby leading to a positive user experience (Cho and Choi 2020).

In his study, Cho (2020) derived affordance factors based on Hartson's classification (2003) to improve the usability of computerised devices and user interfaces. To identify these factors various studies were reviewed: Hartson's affordance classification (2003) but also the concept of affordance in user-centred design proposed by Norman (1988) and several research that presented design principles for improving user-interface usability (Nielsen 1994; Mandel 1997; Blair-Early and Zender 2008).

The design principles of affordance and user interface were classified into the four categories proposed by Hartson (2003): cognitive, physical, functional, and sensory affordance. Similar content elements were grouped to derive the subdivided affordance factors for each category. This resulted in a total of sixteen affordance factors, with four factors for each category, summarizing the characteristics of the items in each group (Cho and Choi 2020).

Following the definition of affordance factors, Cho (2020) further analysed them to develop guidelines for enhancing the usability of active devices and user interfaces.

3.1 Cognitive Affordance Factors

Cognitive affordances involve design features that provide visual clues or information to enable the prediction of how a task is performed or the results (Cho and Choi 2020). Users should be able to intuitively understand the current state of smart systems and how to operate them (Edwards and Grinter 2001).

The affordance factors identified by Cho (2020) are:

CA1) A design that eliminates unnecessary complexity.

CA2) Button names and menu names that can predict functions.

CA3) Providing easy-to-understand information.

CA4) Easy-to-understand icons.

The guidelines proposed by Cho (2020) to improve cognitive affordances are:

- Apply a simple design consisting of buttons and displays of main functions.
- Hide infrequently used functions.
- Organize menus hierarchically.
- Group related content together.
- Use familiar and concise button names without abbreviations or jargon.
- Provide key information concisely using familiar terms.
- Provide information that matches the menu names.
- Use button names that enable prediction of the function.
- Use button names that enable clear recognition of the operation target.
- Use universal icons with text labels on buttons.

3.2 Physical Affordance Factors

The concept of physical affordances refers to a design that helps users perform physical actions so that they can perform tasks easily. The design of active devices should be convenient to operate in terms of size, shape, and location and should minimize repetitive actions by users when performing tasks (Cho and Choi 2020).

The affordance factors identified by Cho (2020) are:

PA1) Supporting various methods of operation.

PA2) Straightforward control method.

PA3) Easy-to-manipulate physical design (size, shape, location).

PA4) A design with minimal repetitive control.

To enhance physical affordances, Cho (2020) proposed the following principles:

- Apply a multimodal interface to vary the input and output methods.
- Allow control of the device with a few simple actions.
- Apply easy-to-learn and easy-to-remember device operating methods.
- Keep the interface consistent so that the same interactions lead to the same results.

3.3 Function Affordance Factors

Functional affordances refer to a design that helps users achieve the desired results. The design increases accessibility to frequently used functions and provides customised settings to help users effectively accomplish the desired tasks. It should also provide feedback on the results of user manipulation and remove or disable elements that can cause mistakes or risks (Cho and Choi 2020).

The affordance factors identified by Cho (2020) are:

FA1) Accessibility to frequently used functions.

FA2) User-customised setting functions.

FA3) Providing feedback on the result of user manipulation.

FA4) Designed to minimise mistakes and risks.

Cho's (2020) instructions to improve functional affordance are:

- Increase accessibility by providing shortcut buttons for frequently used or emergency functions.
- Allow users to set customised modes and easily control each mode.
- Allow users to customise the interface to their preferences.
- Allow users to store and easily implement their preferred modalities.
- Provide feedback that indicates the results of actions for every manipulation.
- Provide visual feedback that indicates the selected function.
- Provide informative feedback that provides information on how to resolve an error.
- For safety-related functions provide multiple types of feedback (e.g., visual, auditory, and tactile feedback) to ensure that the feedback is recognised.
- Provide "Back" and "Cancel" functions to easily reverse actions.
- Provide help where it is easily accessible.

3.4 Sensory Affordance Factors

Sensory affordances focus on designs that assist or encourage users to see, hear, and feel. The user interface's text, buttons, and icons should be easily distinguishable and noticeable against the background. Important elements should be highlighted to reduce risks and user errors. Services should be provided using visual, auditory, or tactile elements in suitable forms (Cho and Choi 2020).

The affordance factors identified by Cho (2020) are:

SA1) Legibility of text.

SA2) Sufficient colour contrast.

SA3) Emphasis on elements that are important or require attention.

SA4) Adequacy of the presentation medium.

Cho (2020) proposed the following principles:

- Avoid using decorative fonts.

- Do not use more than three fonts on the same page.
- The brightness contrast between the text and the background should be at least 4.5:1.
- If text can be magnified, the contrast between the text and the background should be at least 3:1.
- Apply a colour with high visibility to text that notifies of caution, error, or danger.
- Do not use more than four colours on one screen.
- The buttons for emergency functions should be distinguished from other buttons by colour to be noticeable.
- Differentiate the size, colour, and thickness of the font according to the hierarchy of information.

Chapter 3

ACCEPTANCE AND ADOPTION PROCESS

Examining the users' acceptance of new products and services is one of the essential activities leading to the success of products and or services in competitive markets. Acceptance models are theoretical frameworks designed to understand and explain the factors influencing the adoption and use of new technologies. By leveraging these models, researchers can better understand users' needs and behaviours leading to effective implementation and widespread acceptance and usage of new technologies.

One of the most spread and influential theories is the Technology Acceptance Model by Davis (1989). Over the years several other theories have emerged, including the Diffusion of Innovations Theory by Rogers (1995), the Unified Theory of Acceptance and Use of Technology (2003) and the Value-based Adoption Model (2007).

1. Technology Acceptance Model

The Technology Acceptance Model (TAM) proposed by Davis in 1989 is the most widely applied and validated model of users' acceptance and usage of technology among scholars (Venkatesh and Davis 2000). The TAM model is based on socio-psychological theories and assumes that the usage of technology is decided by consumers' behaviour intention.

The model, reported in Figure 3, is composed of four main constructs: perceived usefulness, perceived ease of use, attitude toward using and behavioural intention to use.

According to this theory, two factors influence consumers' behaviour: perceived usefulness and perceived ease of use. Perceived usefulness is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" (F. D. Davis 1989; F. D. Davis, Bagozzi, and Warshaw 1989), while perceived ease of use is defined as "the degree to which a person believes that using a particular system would be free of effort" (F. D. Davis, Bagozzi, and Warshaw 1989; F. D. Davis

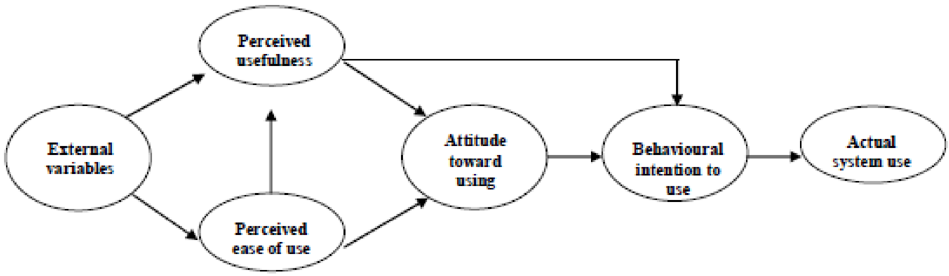

FIGURE 3: TECHNOLOGY ACCEPTANCE MODEL

1989). Both factors are influenced by external variables. Common external elements include the nature of the technology and the availability and implementation of training courses for its use (Bernsdorf et al. 2016).

Ayeh et al. (2013) suggests that incorporating context-specific external variables into the Technology Acceptance Model (TAM) framework can make it more relevant to the specific context of use.

Attitude toward using refers to the response of a user when facing a specific concept or target (Vijayasarathy 2004). It reflects how a person feels about the prospect of using a technology. The behaviour intention to use denotes the user's intention to use the system in the future, it is a predictor of actual system usage. It indicates the degree to which a person has formulated conscious plans to use the system. If the user has a positive attitude toward a new system, then he or she will exhibit stronger intentions to use it (Shih 2004).

According to TAM, consumers' behavioural intention to use is primarily influenced by their attitude toward using a system. This attitude, in turn, is shaped by perceived usefulness and perceived ease of use. Various external factors can impact these perceptions within a system, thereby affecting both attitude toward the use and behavioural intention to use, which ultimately influences the actual usage of the system (F. D. Davis, Bagozzi, and Warshaw 1989; F. D. Davis 1989). TAM analysis indicates that perceived usefulness directly influences behavioural intention to use, while perceived ease of use exerts an indirect influence on behavioural intention to use through its mediation of perceived usefulness.

The model has been applied in different fields to evaluate consumer's acceptance and adoption of online learning (Y.-C. Lee 2008; Persico, Manca, and Pozzi 2014; Sadeck 2022), smartphones (Y. Park and Chen 2007; Joo and Sang 2013), electronic medical system (Holden and Karsh 2010), e-shopping (Ha and Stoel 2009; Cerniauskaite, Sabaitytė, and Leonavičienė 2020), wearable technology (Turhan 2013; Kalantari 2017) smart home technologies (Liu and Chou 2020; Y. Yang et al. 2023) and social robots (Krägeloh et al. 2019).

The model has been constantly studied and expanded. A second version of the model and the Unified Theory of Acceptance and Use of Technology (2003) are the major evolutions of Davis's work.

1.1 Technology Acceptance Model 2

Venkatesh and Davis (2000) extended the original TAM model to explain perceived usefulness and intention to use in terms of social influence and cognitive instrumental processes. Different external variables were added to the model: subjective norms, voluntariness, experience, image, job relevance, output quality, and result demonstrability.

The Technology Acceptance Model 2, as shown in Figure 4, illustrates the influence of three social factors (subjective norm, voluntariness, and image) and cognitive instrumental processes (job relevance, output quality and result demonstrability) (Venkatesh and Davis 2000) on an individual's decision to adopt or reject a new system.

A subjective norm is defined as a "person's perception that most people who are important to him think he should or should not perform the behaviour in question" (Fishbein and Ajzen 1975). Even if a person is not personally inclined toward a behaviour, they may still choose to do it if they believe that influential individuals think they should and they are motivated to comply with them. To differentiate between mandatory and voluntary usage settings, the concept of voluntariness has been introduced, defined as "the extent to which potential adopters perceive the decision to adopt as non-mandatory" (Agarwal and Prasad 2007; Hartwick and Barki 1994; Moore and Benbasat 1991). It has been found that experience has a positive influence on both variables.

Another important factor to be considered is the impact of image and social influence. If influential members of a person's social circle believe that he or she should engage in a certain behaviour, then doing so will likely improve that person's standing within the group (Blau 1964; KIESLER 1969; Pfeffer 1982). Image, in this context, refers to "the extent to which the use of an innovation is perceived to enhance one's status in one's social system" (Moore and Benbasat 1991).

Job relevance refers to an individual's perception of how applicable a system is to their job (Venkatesh and Davis 2000). People also consider how well the system performs tasks, which is known as perceptions of output quality (Venkatesh and Davis 2000). Result demonstrability, as defined by Moore

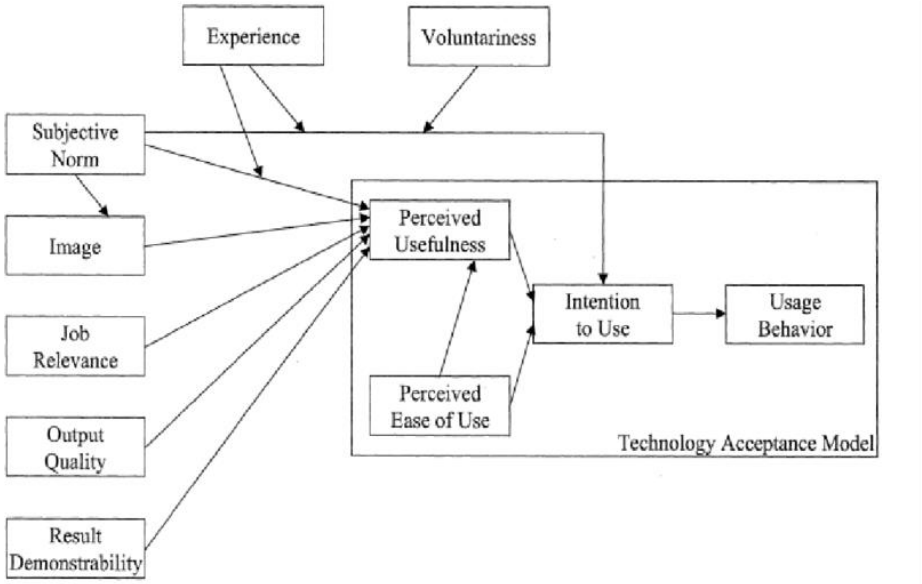

FIGURE 4: TECHNOLOGY ACCEPTANCE MODEL 2

and Benbasat (1991), refers to the tangibility of the results of using the innovation and directly influences perceived usefulness.

The proposed TAM2 model includes social influence processes and cognitive instrumental processes as determinants of perceived usefulness and intention to use. The model also suggests that the strength of social influence processes on perceived usefulness and intention to use will decrease with increasing experience over time.

2. Unified Theory of Acceptance and Use of Technology

The Unified Theory of Acceptance and Use of Technology (UTAUT) was elaborated by Venkatesh et al. (2003). This model, reported in Figure 5, integrates the TAM and the more advanced TAM2 model with other technology acceptance research models.

The UTAUT model uses the term "performance expectancy" to refer to perceived usefulness and "effort expectancy" to refer to perceived ease of use. Performance expectancy is described as "the extent to which an individual believes that using a specific technology will help them achieve performance", while effort expectancy is defined as "the ease associated with using a particular technology" (Venkatesh et al. 2003).

This theory also includes two other key concepts: social influences, which relate to norms and image regulation, and facilitating conditions, defined as

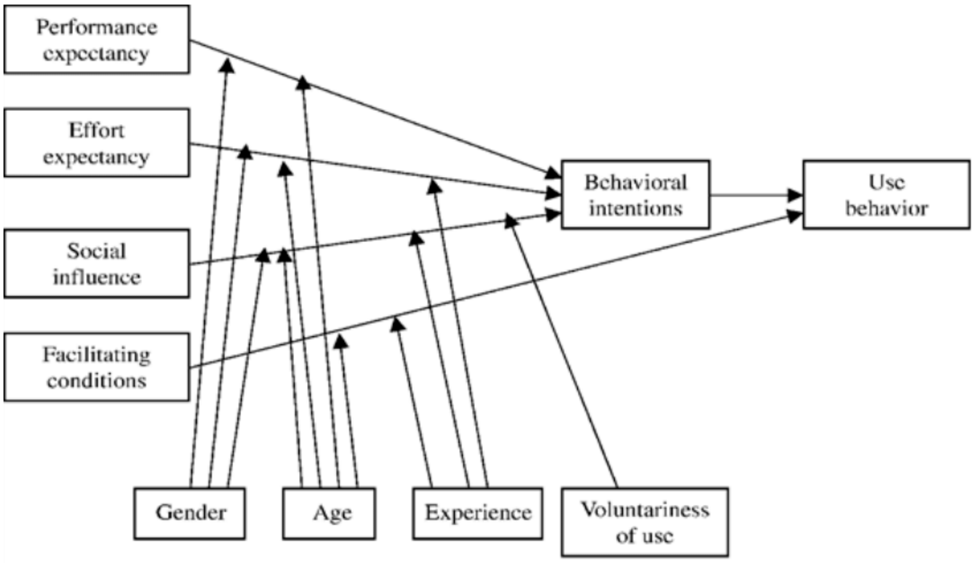

FIGURE 5: UNIFIED THEORY OF ACCEPTANCE AND USE OF TECHNOLOGY

"the extent to which an individual believes that there is an organizational and technical infrastructure to support the use of the system" (Venkatesh et al. 2003).

Additionally, four control determinants (gender, experience, age, and voluntariness of use) help mediate the effects of the entire process (Shachak, Kuziemsky, and Petersen 2019).

2.1 Unified Theory of Acceptance and Use of Technology 2

Venkatesh et al. (2012) extended the UTAUT model by incorporating three new key constructs: hedonic motivation, price value, and habit since these constructs play an important role in consumers' behavioural intention to use new technologies. The newly introduced model is known as UTAUT2, an acronym denoting the second version of the Unified Theory of Acceptance and Use of Technology (Figure 6).

Hedonistic motivation is defined by the authors as "the fun or pleasure derived from using a technology" (Venkatesh, Thong, and Xu 2012). The model considers the acquisition costs of technology in the consumer context, as users bear the expenses themselves. An additional determinant is price value defined as the "consumers' cognitive trade-off between the perceived benefits of the application and the monetary costs for using them" (Venkatesh, Thong, and Xu 2012). Another construct presented in the model

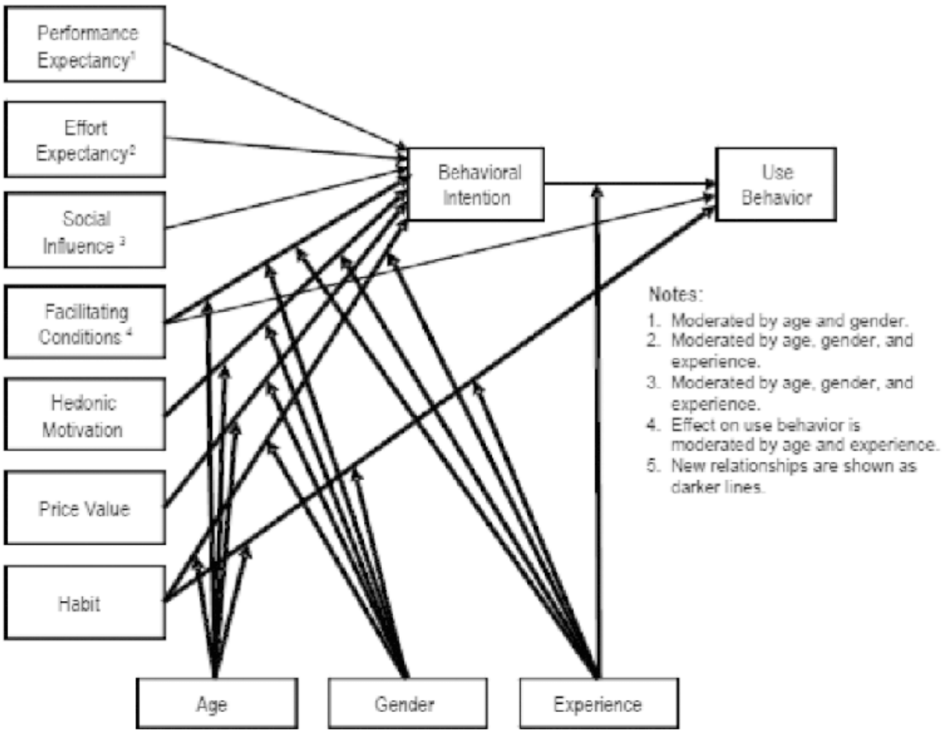

FIGURE 6: UNIFIED THEORY OF ACCEPTANCE AND USE OF TECHNOLOGY 2

is habit, defined as "the extent to which people tend to perform behaviours automatically because of learning" (Venkatesh, Thong, and Xu 2012).

3. Value-based Adoption Model

Kim et al. (2007) proposed the Value-based Adoption Model to explain the acceptance of new ICT, technologies that the Technology Acceptance Model was limited in explaining. New ICT users should not be recognised as simply technology users, but also as consumers.

VAM, reported in Figure 7, states that perceived value is the main determinant of the adoption of new ICT. The model saw benefits (usefulness and enjoyment) and sacrifice (technicality and perceived fee) as the main factors of perceived value and analysed intention to use.

Adoption decisions are made based on a cost-benefit paradigm, by comparing the uncertain benefits and costs of choosing an alternative. This reflects the decision-making process based on the monetary price, representing the end user's evaluation of the overall utility of products and services (Lin et al. 2012).

Perceived benefits and sacrifices are categorized into external and cognitive benefits, internal and affective benefits, monetary sacrifice, and non-

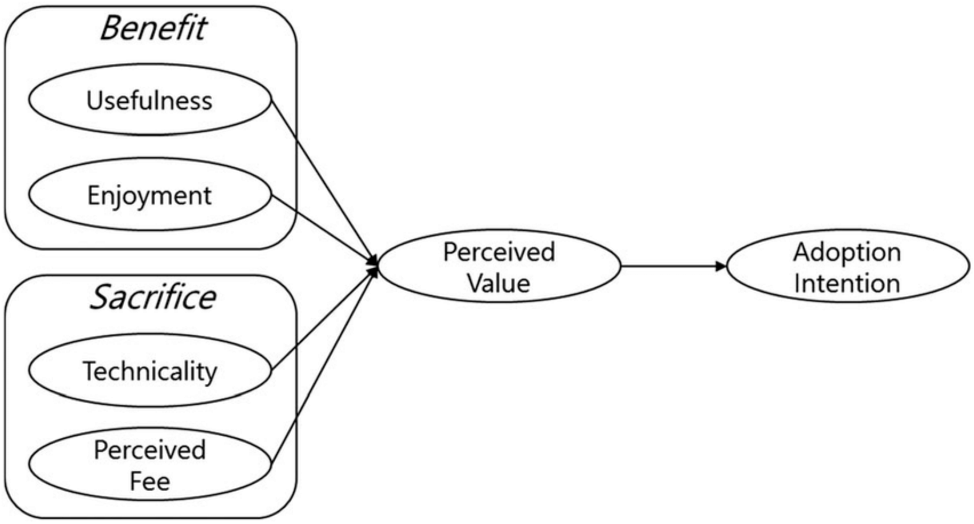

FIGURE 7: VALUE-BASED ADOPTION MODEL

monetary sacrifice. External and cognitive benefits are gained from the performance of an activity to achieve a specific goal. Intrinsic and affective benefits are the benefits gained from engaging in activities without any enforced intervention. Monetary sacrifice is the actual price paid for products and services, and users generally measure utility based on perceptions of the actual price paid, seeking to maximize the "value" of the products and services (Boksberger and Melsen 2011; Kim, Chan, and Gupta 2007). Non-monetary sacrifice refers to intangible costs paid for products and services such as time, burden, and risk, and will indirectly affect the perceived value of products and services (Kim, Chan, and Gupta 2007).

4. Innovation Diffusion Theory

Innovation Diffusion Theory proposed by Rogers in 1995 explains the underlying factors that affect the dissemination of innovations and new technologies in societies. Innovation diffusion is a process of five stages: knowledge, persuasion, decision, implementation and confirmation (Rogers 1995) that occurs thanks to communication channels over a period of time among the members of a similar social system. Individuals pass from obtaining knowledge about an innovation to forming an attitude about it, this attitude will then impact the individual’s decision to accept or reject the innovation at each step of the process.

In the knowledge phase, individuals are first introduced to an innovation but lack information about it and have not yet been inspired to find out more.

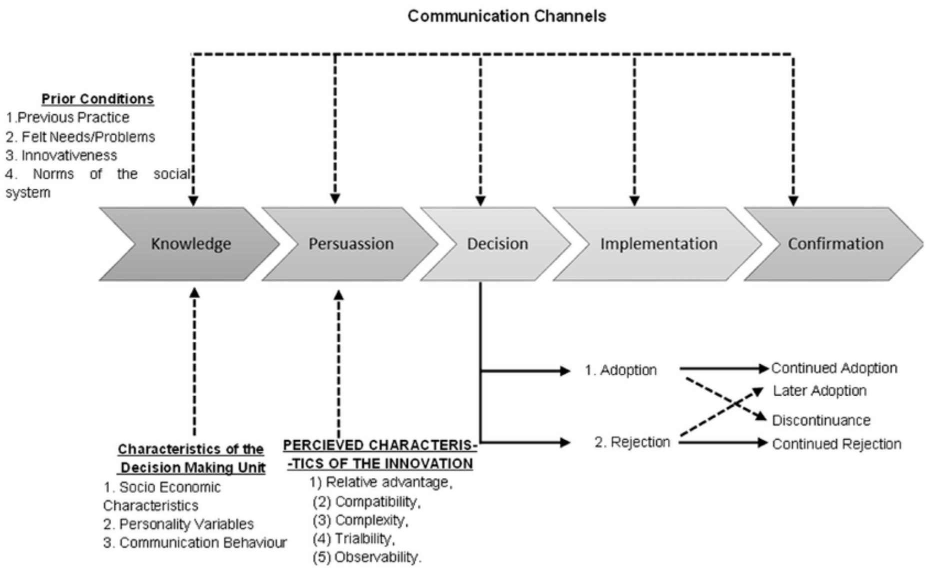

FIGURE 8: INNOVATION DIFFUSION THEORY

In the persuasion phase, individuals become interested in the technology and actively seek related information.

In the decision phase, individuals consider the change, weigh the advantages and disadvantages of using the innovation, and decide whether to adopt or reject the technology.

During the implementation phase, individuals employ the innovation to varying degrees depending on the situation and determine its usefulness.

In the continuation phase, individuals finalize the decision to continue using the innovation and seek reassurance that the decision and implementation are beneficial.

5. The Relationship Between Affordance and Acceptance

Seet and Goh (2012) proposed a study on the correlation between affordance and acceptance of an e-reader device as a collaborative learning system. This study introduced the concept of composite affordance in a revised Technology Acceptance Model to investigate users' acceptance of the device.

According to the authors, the decision to use a system as a cognitive process can be influenced by an overall assessment of the various affordances of the system. The model conceptualized in the referenced work is reported in Figure 9.

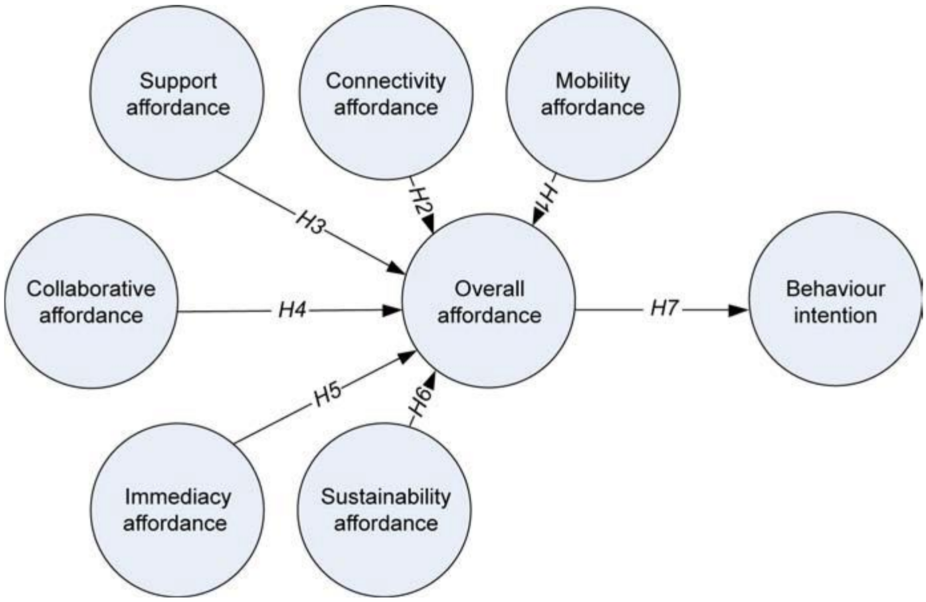

FIGURE 9: REVISED TAM WITH AFFORDANCE CONSIDERATION

In the analysed case study of an e-reader device, the identified affordances include mobility, connectivity, support, collaborative, immediacy, and sustainability affordance (Seet and Goh 2012).

Mobility affordance is the possibility for learners to be mobile and collaborate from any location. Connectivity affordance refers to the ability of students to connect to the internet. Support affordance concerns the opportunity for students to be supported with tools in their learning activities. Collaborative affordance is defined as the opportunity for learners to effectively discuss and exchange ideas with each other. Immediacy affordance concerns the opportunity for immediate communication of questions and ideas between students. Lastly, sustainability affordance refers to the ability of students to collaborate and view the e-reader's display over a long period.

These aspects represent the potential actions perceived by the user. The authors hypothesised and subsequently validated, through the support of a questionnaire, that the overall assessment of affordances directly influences the intention to use.

All the hypotheses were supported except for the sustainability affordance. One possible reason is that users were accustomed to colour displays, whereas e-reader devices available at the time of the research only featured greyscale displays. Another likely explanation is that users expected collaborative learning contexts to be short-term, making long-term sustainability incompatible with their current collaborative practices. Additionally, collaborative learners may prefer face-to-face discussions, further highlighting this incompatibility.

Support affordance and collaborative affordance were found to be the two most important factors contributing to the acceptance of such a system. Therefore, a well-designed visible support affordance and collaborative affordance are essential. System designers should emphasise creating a wide range of intuitive and visible support affordances while enhancing or complementing collaborative learning affordances. The design of an integrated web browser is particularly important, as it establishes the foundation for enabling web-based collaborative learning with e-reader devices.

Chapter 4

THE CASE STUDY

Figure 10 (Monti et al. 2024) highlights various proposed case study examples that identify four distinct types of artefacts with the same function, one for each macro category defined by the quadrants of the Cartesian axes. These case studies are colour-coded according to their declared functions (e.g., cleaning the house, independent driving, customising garments, having clean clothes, exercising with correct posture, and time management).

For this thesis, the chosen case study focuses on "getting the house clean," specifically examining the digital transformation from traditional vacuum cleaners to their autonomous counterparts.

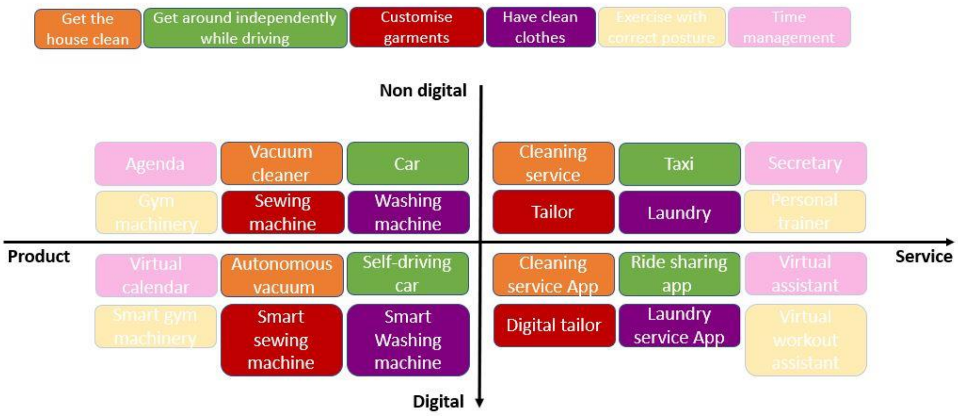

FIGURE 10: ROBOTIC VACUUM CLEANER CASE STUDY

This thesis focuses on the robotic vacuum cleaner case study and aims to analyse how consumers switch between two substitute artefacts: a non-digital product (traditional vacuum cleaners) and a digital one (robotic vacuum cleaners). By integrating the affordance theory with the Technology Acceptance Model (TAM), this case study aims to provide a comprehensive understanding of the factors that influence the adoption and usage of robotic vacuum cleaners. The affordances of robotic vacuum cleaners are considered alongside the traditional TAM constructs to examine how these perceived features impact user acceptance and satisfaction. By exploring these aspects, the case study aims to shed light on the complex interplay between technology features and user perceptions, ultimately contributing to the broader understanding of technology adoption in the context of smart home devices.

1. The Evolution from Traditional to Robotic Vacuum Cleaners

Since the early 21st century, robots have steadily become a part of the domestic environment, transforming everyday household tasks through automation and advanced technology. These innovations range from robotic vacuum cleaners and lawnmowers to more complex home assistants capable of managing various chores and providing companionship. The integration of robots into homes has not only increased efficiency and convenience for users but also paved the way for smart home ecosystems where devices communicate and work together seamlessly.

This shift represents a significant milestone in technological advancement, as robots transition from industrial and specialised applications to becoming integral components of daily life, enhancing the quality and ease of home management.

There are significant differences between industrial and domestic robots. Firstly, the environment in which domestic robots operate is much less restricted than in an industrial setting and involves a closer interaction between robots and humans (Dario, Guglielmelli, and Laschi 2001). The transition from the controlled environments of laboratories and factories to more open settings necessitates a revaluation of the design, functionality, and interaction capabilities of robots. They must be able to adapt to unpredictable surroundings and circumstances by possessing advanced sensing, decision-making, and learning abilities to operate close to humans (Khanna and Srivastava 2022). Additionally, they need to be designed to be easily understandable as they will be used by an untrained operator who may have little or no computer experience. Domestic robots also require ad hoc recharging rather than recharging when needed by the batteries. Finally, to be widely adopted, the price point must be low enough to allow regular people to acquire them for everyday tasks (H. Christensen 2001).

One of the main challenges of robots concerning applications for domestic environments and personal use is people's acceptance of robots in their daily lives (Rayna 2008). The potential applications are endless, but the task domain can be divided into three major categories as reported by Christensen (2001) in his study: entertainment, everyday tasks, and assistance to the elderly and the handicapped.

Robots have increasingly entered the domestic environment, leading to the development of various innovative products. The transition from traditional vacuum cleaners (upright and canister types) to robotic vacuum cleaners has revolutionized household cleaning by offering autonomous and efficient cleaning solutions. These devices, equipped with sophisticated sensors and algorithms, have become increasingly popular due to their ability to perform routine cleaning tasks with minimal human intervention.

It is crucial to design robotic technology for long-term acceptance in smart home environments (J. Sung, Grinter, and Christensen 2010). Understanding how people use and adopt a robotic vacuum cleaner, the functionality, user interaction, and general design could be improved to make the product useful, usable and acceptable in the eye of the customer as an everyday tool (Fink et al. 2013).

Sung (2010), starting from Forlizzi and DiSalvo's works (2006, 2007), proposed a long-term field study (Domestic Robot Ecology) focused on understanding how robotic vacuum cleaners became adopted and accepted as a part of the household over time. The process develops over different temporal stages: preadoption, adoption, adaptation and lastly use and retention (Rogers 1995).

- *Pre-adoption*: During this phase, individuals learn how to use the product, form expectations, and develop attitudes (F. D. Davis, Bagozzi, and Warshaw 1989) that impact their later satisfaction (Forlizzi and Disalvo 2006; Forlizzi 2007).

- *Adoption*: This step refers to the initial impressions people form at the moment of purchase or during the first interaction with the product (Rogers 1995).

- *Adaptation*: In this phase, people make changes to incorporate the product into their lives, habits and home environment by experimenting with their functionalities and compatibility with the environment (Rogers 1995).

- *Use and retention*: People start to have a routine with the product and show a tendency toward retention beyond the product's life cycle by upgrading it or changing the model (Rogers 1995).

1.1 Architecture Change and New Dominant Design

Transitioning from traditional vacuum cleaners to robotic ones marks a profound evolution in the realm of home cleaning technology. While

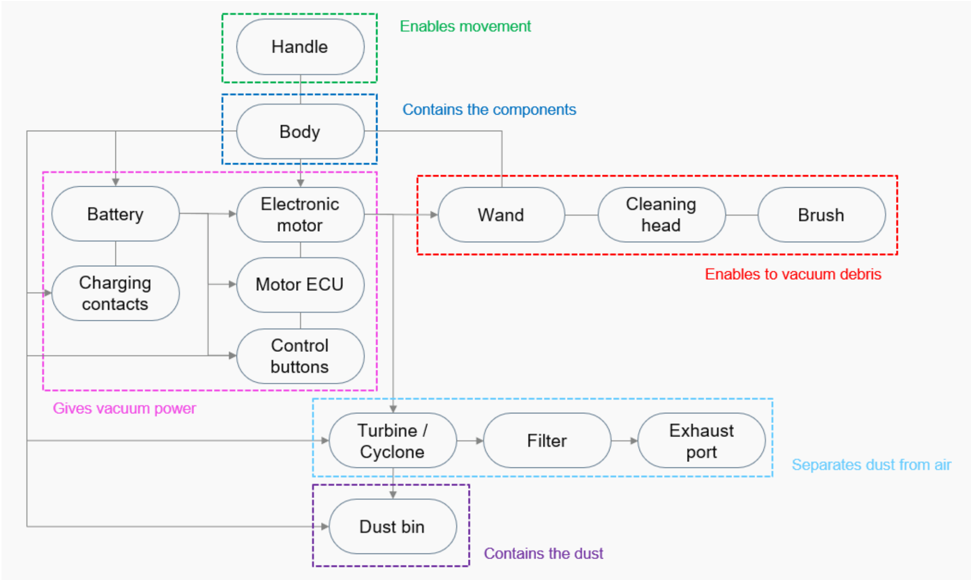

FIGURE 11: TRADITIONAL VACUUM CLEANER ARCHITECTURE

traditional vacuum cleaners have long been relied upon for their manual operation and versatility, robotic vacuum cleaners represent a revolutionary shift towards automation and convenience. This transition is emblematic of broader trends in technological innovation, where advancements in robotics and artificial intelligence converge to redefine everyday household tasks. In this transition, the focus shifts from hands-on user involvement to autonomous cleaning routines guided by sophisticated sensors and intelligent algorithms. It becomes evident that the emergence of robotic vacuum cleaners not only transforms the way we clean our homes but also reflects a paradigm shift in the very nature of home cleaning technology.

Robotic vacuum cleaners have revolutionized cleaning tasks by minimizing human intervention. Their architecture (Figure 12) is different from the one of traditional vacuum cleaners (Figure 11). Typically, these robots commence their cleaning journey by mapping the room and assessing its size either through infrared signals or laser scanning. Algorithms then dictate their cleaning path, leading them to traverse in varied patterns until achieving comprehensive coverage. Some cleaners adopt a more systematic approach, creating a square grid of the room and methodically cleaning within it. During their cleaning cycles, robots identify obstacles using front bumpers or employ advanced methods like acoustic wave detection to prevent collisions. They use one or more brushes to enhance particle suction, often including a roller brush for efficient cleaning. Additionally, many models feature side brushes to tackle corners and edges effectively. These robots, equipped with cliff sensors, avoid falls from heights such as stairs. Operating on rechargeable batteries, their cleaning duration depends on battery capacity, with robots returning to a base station for recharging as needed. With a front wheel enabling rotation and side wheels facilitating

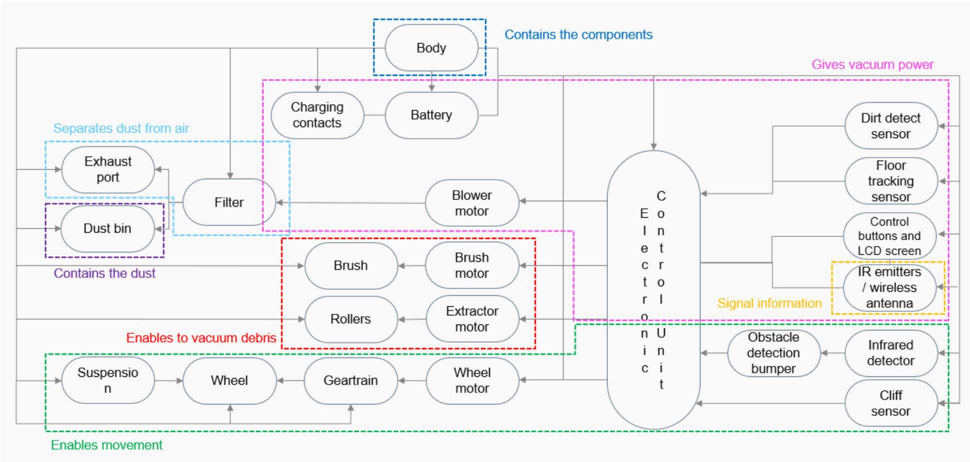

Figure 12: Robotic Vacuum Cleaner Architecture

forward movement, these robots efficiently navigate spaces, ensuring thorough cleaning with minimal human intervention (Radu 2015).

The product architecture that has become widely accepted as the industry standard is referred to as dominant design (Utterback and Abernathy 1975). The dominant design is a fundamental concept in the study of innovation and technology management and sets the benchmark for the market, shaping future innovations and guiding the direction of both product and process development within the industry.

The dominant design of robotic vacuum cleaners typically includes several key components and features:

- *Shape and Size*: Most robotic vacuum cleaners are round or D-shaped to navigate corners and edges effectively. They are generally compact, allowing them to manoeuvre under furniture and into tight spaces.

- *Navigation System*: Advanced navigation systems utilise sensors, cameras, lasers, or a combination of these technologies to map out the cleaning area and avoid obstacles. Some models also incorporate mapping capabilities to optimise cleaning routes.

- *Cleaning Mechanism*: Robotic vacuums typically use brushes and suction to collect dirt, dust, and debris from various floor surfaces. Some models may feature rotating brushes, side brushes, or rubber extractors to loosen and lift dirt efficiently.

- *Battery Power*: Lithium-ion batteries are commonly used to provide power for cleaning cycles. The battery life varies depending on the model and can range from around sixty minutes to several hours. Docking stations are often included for automatic recharging.

- *Dustbin Capacity*: The size of the dustbin determines how much debris the vacuum can hold before needing to be emptied. Most robotic vacuums have a dustbin capacity ranging from 0.3 to 1 litre.

- *Connectivity and Control*: Many modern robotic vacuums offer Wi-Fi connectivity and companion mobile apps, allowing users to control the device remotely, schedule cleaning sessions, and receive notifications. Voice control via virtual assistants like Amazon Alexa or Google Assistant is also becoming increasingly common.

- *Obstacle Detection and Avoidance*: Sensors enable robotic vacuum cleaners to detect obstacles such as furniture, walls, and stairs, allowing them to navigate around these objects without getting stuck or causing damage.

- *Automatic Recharging*: When the battery runs low, or the cleaning cycle is complete, robotic vacuums typically return to their docking station automatically to recharge. Some models may also resume cleaning from where they left off once recharged.

- *HEPA Filtration*: High-efficiency particulate air (HEPA) filters are often integrated into robotic vacuum cleaners to capture fine dust particles and allergens, improving indoor air quality.

- *Maintenance and Accessibility*: The design often includes features for easy maintenance, such as removable and washable filters, brushes, and wheels. Accessibility to components like the battery and dustbin for replacement or cleaning is also considered.

These features constitute the dominant design of robotic vacuum cleaners, but continuous innovation and improvements are ongoing in the market to enhance performance, efficiency, and user experience.

1.2 Defining the Innovation

The analysis of architectural changes and dominant design has paved the way for identifying the type of innovation that the autonomous vacuum cleaner represents compared to the traditional model.

Innovation taxonomy provides a structured framework to navigate the complex landscape of innovation. By categorising and understanding the different forms of innovation, organizations can better manage their innovation strategies, drive growth, and maintain a competitive edge in the ever-evolving market.

The model proposed by Henderson and Clark (1990) is based on a two-by-two matrix that classifies innovations according to their impact on product architecture and the relationships between components. Depending on whether the innovation affects the underlying technology or the product architecture, it can be categorized as *modular innovation*, *radical innovation*, *incremental innovation*, or *architectural innovation*. The innovation in robotic vacuum cleaners is considered radical due to the substantial advancements in both underlying technology and product architecture. These breakthroughs go far beyond incremental improvements, introducing groundbreaking features and capabilities that redefine what these devices can do and how they are used. Key innovations include advanced AI and machine learning algorithms for better navigation and adaptability, integration of LiDAR and visual SLAM for precise mapping and obstacle avoidance, self-cleaning mechanisms, automatic dirt disposal systems, multi-functionality with mopping and air purification, smart home integration, and eco-friendly designs. These innovations collectively transform the vacuum cleaner from a cleaning tool into a highly intelligent, efficient, and versatile household assistant.

Innovation can be defined as *incremental* or *radical* (Dutton and Thomas 1984) by looking at the technical features of the product and whether the innovation significantly changes the technical trade-offs that define it. The robotic vacuum cleaner innovation is a radical one due to its shift from manual to automated operation, advanced navigation and sensing technologies, sophisticated user interfaces, optimised energy efficiency, and new maintenance requirements.

Innovations can be *competence enhancing* or *competence destroying* (Anderson and Tushman 1990) based on the knowledge that is required to develop new products. The robotic vacuums are a competence-destroying innovation. Firms necessitate the development of new competencies related to artificial intelligence and machine learning. This innovation requires organizations to set aside their existing knowledge and acquire new skills to effectively operate the technology. Moreover, users of the product must familiarise themselves with a new interface and gain new skills to interact with the device.

Innovations can also be *core* or *peripherical* depending on whether they affect the core functionality of the product or ancillary ones. The primary purpose of a robotic vacuum cleaner is to perform vacuuming tasks, and its functionality remains unaffected by the various innovations that have been introduced in the field. The scope of innovation is primarily limited to the way the device moves around. Thus, the innovation of robotic vacuum cleaners is largely peripheral.

Finally, innovations can be *sustaining* or *disruptive* (C. M. Christensen 1997). A sustaining innovation will not lead to significant change in competitor's positions and market share, while disruptive innovation will lead to significant changes. The advent of robotic vacuum cleaners has been identified as a disruptive innovation. Companies that have traditionally held a dominant position in the industry found themselves struggling to keep pace with the rapid changes brought about by this disruptive technology, while smaller firms, new entrants, and startups had a newfound opportunity to establish themselves as leaders in the field.

The robotic vacuum cleaner innovation places itself in the competitive phase of the simplified linear chain of innovation. The market for robotic vacuum cleaners is mainly dominated by key players such as iRobot, Ecovacs, SharkNinja, Xiaomi, and Roborock. Each of these companies contributes to the industry's growth through innovation and strategic positioning ('Robotic Vacuum Cleaner Market Share Worldwide from 2014 to 2020, by Brand' 2024). These principal market players drive the industry forward through continuous innovation, extensive research and development, and a deep understanding of consumer needs, each bringing unique strengths to the competitive landscape of robotic vacuum cleaners.

2 Affordance Identification

After defining the type of innovation represented by autonomous vacuum cleaners compared to traditional models, it becomes evident that human-robot interaction plays a pivotal role in their adoption and effectiveness. The seamless integration of intuitive controls, responsive sensors, and efficient task execution enhances user experience and determines these advanced technologies' practical utility and market acceptance.

Human-robot interaction is a field of study that focuses on how humans and robots engage with each other. This area of research encompasses the design, evaluation, and understanding of robotic systems in contexts where humans utilise them or operate alongside them (Khanna and Srivastava 2022). The features of the robots should be shaped according to the environment they operate in, in addition to users' needs and expectations (Yapici 2022).

Linjawi and Moore (2018) proposed a theoretical model to capture robot features and their capabilities in the robotic domain to match them according to the requirements of specific applications.

Robotic vacuum cleaners are technological devices with a very high interaction rate within their operators (Forlizzi 2007). Crucial for the user experience and product acceptance is the design of appropriate interaction between humans and robots. Not only should technological affordance take credit, but also social aspects of human-robot interaction must be considered to establish human-oriented robots (Yapici 2022).

User interfaces for interaction between smart products and users are often not user-friendly, causing potential difficulties and inconvenience for the user. To design user-centred products, usability must be improved based on the concept of affordance (Cho and Choi 2020) considered in terms of physical, visual, auditory, and tactile aspects. Norman, in The Psychology of Everyday Things (1988), mentioned that "the term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could be used … Affordances provide strong clues to the operations of things. Plates are for pushing. Knobs are for turning. Slots are for inserting things into. Balls are for throwing or bouncing. When affordances are taken advantage of, the user knows what to do just by looking: no picture, label, or instruction needed" (D. Norman 1988).

In this thesis, affordance will be evaluated based on Hartson's classification, as employed in studies by Cho (2020) and Wu et al. (2022), to enhance user-product interaction. This approach encompasses four types of affordances: cognitive, physical, functional, and sensory. Emotional affordances are also considered, as they significantly influence human-technology interactions (T. Park and Lim 2018).

Cognitive affordances will be assessed by examining the clarity and intuitiveness of controls and feedback mechanisms. Physical affordances will focus on the ease of performing physical actions, such as setting up and maintaining the device. Functional affordances will be evaluated based on how effectively the device helps users achieve their cleaning goals. Sensory affordances will consider the role of visual, auditory, and tactile elements in enhancing user experience.

Emotional affordances will be evaluated using Norman's model (2004), which incorporates emotion into the design process. Building on Norman's work, several studies have explored design variables across the three levels

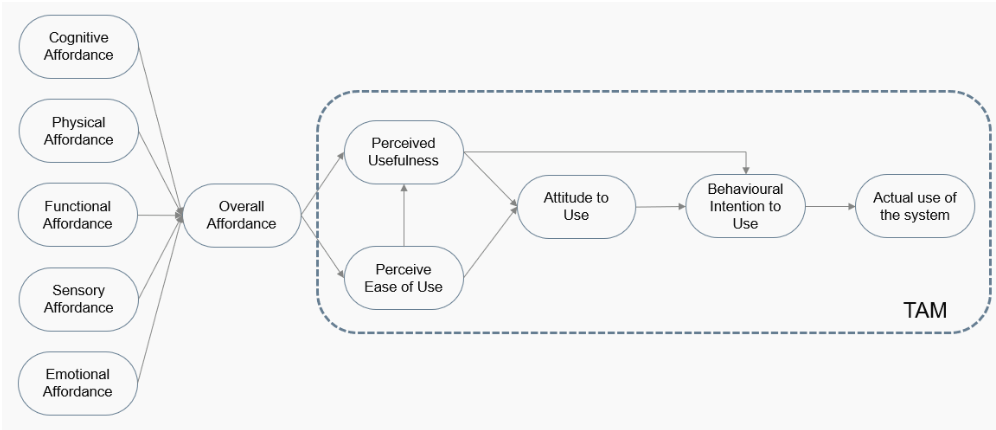

FIGURE 13: THE HYPOTHESIZED MODEL

of emotional affordance: visceral, behavioural, and reflective (T. Park and Lim 2018). This thesis leverages the works of Van Gorp and Adams (2012) and Sanders (1992). They categorize the visceral level as relating to aesthetics. The behavioural level involves the interaction between the user and the product, focusing on how easily the user understands, learns, and utilises the product. The reflective level examines the product's function, evaluating how well it accomplishes its intended purpose.

By leveraging the affordance factors proposed by Cho (2020) and Norman's (2004) model as described in section 3, this work aims to improve the usability of robotic vacuum cleaners and their user interfaces, leading to more user-centred products.

3 The Model

The Technology Acceptance Model (TAM), developed by Davis (1998), postulates that perceived ease of use and perceived usefulness are the primary determinants of technology acceptance. It is the most widely utilised and acknowledged framework for understanding and explaining the key factors influencing the adoption and use of new technologies. Numerous prior studies (Seet and Goh 2012; Bernsdorf et al. 2016; Liu and Chou 2020; E. Park et al. 2017; A. Shuhaiber, I. Mashal, and O. Alsaryrah 2019; Shuhaiber and Mashal 2019; J. Stragier, L. Hauttekeete, and L. De Marez 2010; Y. Yang et al. 2023; Yu and Sung 2023) have employed TAM to investigate the acceptance of various technologies within the smart home environment, demonstrating its robustness and versatility in capturing the dynamics of technology adoption in diverse contexts. The model proposed in this thesis, presented in Figure 13, builds upon the Technology Acceptance Model (TAM) to examine the relationship between affordance and the adoption of robotic vacuum cleaners in domestic settings. By integrating the concept of composite affordance, as introduced by (Seet and Goh 2012), the model incorporates composite affordance as an external variable. This approach allows for an analysis of how various affordances collectively influence the acceptance and integration of robotic vacuum cleaners into everyday household routines.

The primary objectives of this experiment are to assess and evaluate the correlation between the affordances of robotic vacuum cleaners and their acceptance in domestic settings to validate the extended TAM framework incorporating composite affordance as an external variable.

The key variables in this study are:

- Perceived Ease of Use: The degree to which a person believes that using the robotic vacuum cleaner will be free of effort.
- Perceived Usefulness: The extent to which a person believes that using the robotic vacuum cleaner will enhance their household cleaning.
- Composite Affordance: A measure of the combined affordances provided by the robotic vacuum cleaner, influencing both perceived ease of use and perceived usefulness.
- Attitude to Use: Individuals are voluntary to accept robotic vacuum cleaners and have an overall positive attitude about it.
- Intention to Use: The likelihood that a person will purchase, recommend and use the robotic vacuum cleaner in their home.

The following hypotheses are proposed:

H1: Attitude toward robotic vacuum cleaners significantly affects the intention to use the technology.

H2: Perceived usefulness of robotic vacuum cleaners significantly affects the intention to use the technology.

H3: Perceived usefulness of robotic vacuum cleaners significantly affects the attitude toward the technology.

H4: Perceived ease of use of robotic vacuum cleaners significantly affects the attitude toward the technology.

H5: Perceived ease of use of robotic vacuum cleaners significantly affects the perceived usefulness of the technology.

H6: Composite affordance positively influences both perceived ease of use and perceived usefulness of the technology.

H7: Cognitive affordance is positively related to overall affordance.

H8: Physical affordance is positively related to overall affordance.

H9: Functionality affordance is positively related to overall affordance.

H10: Sensory affordance is positively related to overall affordance.

H11: Emotional affordance is positively related to overall affordance.

4 Design of the Experiment

This study employs a quantitative research design, which is well-suited for testing the proposed hypotheses and analysing the relationships between the variables. The research proposes a structured questionnaire to gather data and the desired sample characteristics to ensure representativeness. Subsequent validation will be left to future studies.

4.1 The Questionnaire

The structured questionnaire is developed based on established TAM scales and the concept of composite affordance introduced by Seet and Goh (2012). The survey will include items to measure perceived ease of use, perceived usefulness, attitude and intention to use a robotic vacuum cleaner and composite affordance. The collected data will be analysed using statistical techniques such as regression analysis and structural equation modelling (SEM). These methods will allow for the testing of the proposed hypotheses and the examination of the relationships between the variables.

Before the main data collection, a pilot test could be conducted with a small subset of participants. This step is essential to ensure the clarity and reliability of the survey items and to make any necessary adjustments based on the feedback. Before the data collection participants could also interact with a robotic vacuum cleaner in a controlled environment, simulating typical household conditions and only after this interaction, they will complete the survey, providing data on their perceptions and intentions regarding the robotic vacuum cleaner.

The questionnaire is divided into three sections. The first section collects background information about the participants. The second section investigates whether the participants own a vacuum cleaner and, specifically, if they own a robotic one, including the reasons for their choices.

The third section gathers data on the Technology Acceptance Model (TAM) variables and the external variables related to affordances.

Each variable will be measured using multi-item scales, with responses captured on a seven-point Likert scale ranging from "strongly disagree" to "strongly agree". It is the most appropriate choice for conducting this research based on previous studies (Y. Yang et al. 2023).

The questionnaire will be written in English to match the language of this work, but it will be translated into Italian to better suit the target population. The Italian translation of the questionnaire will be included in Appendix A.

Section 1: Participant Background Information

General information (Jia et al. 2023):

1. Gender:

    - Male
    - Female
    - Prefer not to say

2. Age (Liu and Chou 2020; Ezer, Fisk, and Rogers 2009; Wu et al. 2022):

    - Less than 30
    - 31-40
    - 41-50
    - More than 50

Personal background (Jia et al. 2023):

3. Type of work (Mert 2008; Suschek-Berger 2008; Yu and Sung 2023):

    - Student
    - Employee
    - Self-employed
    - Unemployed
    - Homemaker
    - Retired

4. Do you feel you are well acquainted with technology? (J.-Y. Sung et al. 2008)

    - Strongly Disagree
    - Disagree
    - Neither Agree nor Disagree
    - Agree
    - Strongly Agree

5. Indicate your income bracket (Mert 2008; Suschek-Berger 2008; Ghafurian, Ellard, and Dautenhahn 2023; Yu and Sung 2023; Y. Yang et al. 2023)

    - Up to 15000
    - From 15001 to 28000
    - From 28001 to 50000
    - Over 50000
    - Prefer not to specify

Section 2: Vacuum Cleaner Ownership

6. Do you own a traditional vacuum cleaner? (Palmstedt 2013)

    - Yes
    - No

7. Which kind of vacuum cleaner do you own? (Palmstedt 2013)

    Multiple-choice list with photos for clarity

    - Bagged canister
    - Bag-less canister
    - Bagged upright vacuum cleaner
    - Bag-less upright vacuum cleaner
    - Cordless stick cleaner
    - Battery cordless stick cleaner
    - Robotic vacuum cleaner

8. Have you ever heard about robotic vacuum cleaners? (Zhai et al. 2014)

- Yes
- No

9. Do you own a robotic vacuum cleaner? (Bernsdorf et al. 2016)

    - Yes
    - No

10. For which of the following reasons did you buy or are you planning to buy a robotic vacuum cleaner? (Ghafurian, Ellard, and Dautenhahn 2023; Bernsdorf et al. 2016)

    Multiple-choice list

    - Saving time
    - Saving energy
    - Saving money
    - Ensuring comfort and making things easier
    - Providing peace of mind
    - Improving quality of life
    - Improving health
    - For companionship
    - My general interest in the latest technology
    - Impressing my friends and family
    - Other (specify)
    - No reason

11. If you do not own a robotic vacuum cleaner, specify why (Ghafurian, Ellard, and Dautenhahn 2023; Aykut Coskun, Gül Kaner, and İdil Bostan 2018; Bernsdorf et al. 2016)

    - Cost
    - Privacy and security
    - Uncertainty about effectiveness/benefits
    - Unfamiliarity with the device
    - Other (specify)

12. If you do not own a robotic vacuum cleaner, would you be interested in buying it? (Ghafurian, Ellard, and Dautenhahn 2023; Zhai et al. 2014)

    - Yes
    - No

13. What are your biggest concerns towards smart devices such as robot vacuum cleaners? (Zhai et al. 2014; Ghafurian, Ellard, and Dautenhahn 2023; Aykut Coskun, Gül Kaner, and İdil Bostan 2018; Wickramasinghe and Reinhardt 2020; Bernsdorf et al. 2016)

    Multiple-choice list

    - Security and privacy
    - Reliability of technology
    - Practicality
    - Cost
    - Ease of use/maintenance
    - Other (specify)

Section 3: Technology Acceptance Model (TAM) and Affordances

Responses for each item in Section 3 will be collected using a seven-point Likert scale ranging from "Strongly Disagree" to "Strongly Agree."

14. Perceived Usefulness (F. D. Davis, Bagozzi, and Warshaw 1989; J. Stragier, L. Hauttekeete, and L. De Marez 2010; E. Park et al. 2017; A. Shuhaiber, I. Mashal, and O. Alsaryrah 2019; Y. Yang et al. 2023; Yu and Sung 2023)

    - Using a robot vacuum cleaner increases cleaning efficiency.
    - Using a robotic vacuum cleaner saves me time and effort when carrying out household chores.
    - Using robotic vacuuming improves the quality of life.
    - Using the robotic vacuum cleaner makes it easier for me to perform household chores.
    - Overall, I find the use of robotic vacuum cleaners beneficial for me.

15. Perceived Ease of Use (F. D. Davis, Bagozzi, and Warshaw 1989; J. Stragier, L. Hauttekeete, and L. De Marez 2010; E. Park et al. 2017; A. Shuhaiber, I. Mashal, and O. Alsaryrah 2019; Y. Yang et al. 2023):

    - Using the device is easy.

- Learning to use robot vacuum cleaners is easy for me.
- Using the robotic vacuum cleaner does not require much concentration.
- The interaction with the device is clear and understandable.
- It is easy to make the device do what I want.

16. Attitude to use (F. D. Davis, Bagozzi, and Warshaw 1989; E. Park et al. 2017; A. Shuhaiber, I. Mashal, and O. Alsaryrah 2019; Y. Yang et al. 2023):

    - Using the robotic vacuum cleaner is a good idea.
    - Using the robotic vacuum cleaner is beneficial for me.
    - I like the idea of using the robot vacuum cleaner.

17. Intention to use (F. D. Davis, Bagozzi, and Warshaw 1989; E. Park et al. 2017; A. Shuhaiber, I. Mashal, and O. Alsaryrah 2019; Y. Yang et al. 2023; Yu and Sung 2023):

    - I intend to use the robot vacuum cleaner in the future.
    - I would recommend the robotic vacuums to others.
    - I intend to buy a robotic vacuum cleaner in the future.

18. Cognitive affordance (Cho and Choi 2020):

    - The appearance of the device is simple and has few buttons for the main functions.
    - The names of the buttons and menus are explanatory of the function.
    - The key information is provided clearly and concisely.
    - The icons and texts are easy to understand.

19. Physical affordance (Cho and Choi 2020):

    - The device has several operational modes.
    - The device is easy to control.
    - The device is easy to handle.
    - The buttons are easy to see and reach.

20. Functional affordance (Cho and Choi 2020):

    - Shortcut buttons are provided for the most frequently used functions.
    - Device settings are customisable.

- The device provides immediate feedback on the user's action.
- The device is designed to minimise risks and errors.

21. Sensory affordance (Cho and Choi 2020):

    - Easy-to-read texts are used.
    - There is a contrast between the colour of the buttons and the colour of the device.
    - Important elements or those requiring attention are emphasised.
    - The device provides information adequately.

22. Emotional Affordance (Donald Norman 2004; Sanders 2010; Van Gorp and Adams 2012; Y. Yang et al. 2023; Yu and Sung 2023; E. Park et al. 2017):

    Visceral level

    - The interface of the product is aesthetically designed.
    - The overall look and feel of the robotic vacuum cleaner are visually appealing.

    Behavioural level

    - I think the robotic vacuum provides an easy navigation interface.
    - I think the device can be easily set up.
    - I think getting the robotic vacuum cleaner to do what I want is easy.

    Reflective level

    - Thanks to the robotic vacuum cleaner my house is always clean.
    - The robotic vacuum cleaner can vacuum all kinds of debris.
    - The device can reach corners and narrow spaces.

4.2 The Sample

The study acknowledges that people of different ages make different decisions regarding the use of technological products (Morris and Venkatesh 2000). Middle-aged adults (25-65 years) represent the largest share of the population and, usually being financially self-sufficient, their adoption of robotic vacuum cleaners is crucial for the diffusion and market success of the analysed technology (Wu et al. 2022; Ezer, Fisk, and Rogers 2009).

To ensure broad representation across various demographic and socio-economic groups, a diverse sample of participants will be recruited. This diversity is crucial for generalizing the findings and understanding technology adoption across different household contexts. Given that the author is Italian, the sample will be based on ISTAT data from 2024 to reflect the Italian population accurately.

According to ISTAT data, the Italian population have a nearly equal gender split of 49% male and 50% female. Within the target population:

- People less than 30 years old make up 27% of the population.
- People aged 31-40 years make up 12% of the population.
- People aged 41-50 years make up 14% of the population.
- People with more than 50 years make up 46% of the population.

Multivariate statistical analysis typically requires approximately ten respondents per variable to be analysed simultaneously (Montagna 2024). Given that the study aims to analyse twenty-one variables, the minimum sample size required is two hundred ten respondents (10 respondents per variable x 21 variables = 210 respondents).

Chapter 5

CONCLUSIONS

Diffusion refers to the adoption and gradual spread of new technologies and products within a social system. It involves the dissemination of information and knowledge from early adopters to the broader population, which influences their acceptance and usage patterns. In today's rapidly evolving digital landscape, with the proliferation of digital artefacts, understanding the evolution of these concepts and the dynamics of their processes is pivotal in determining product success in competitive markets.

This study employs a quantitative research design to explore the factors influencing the acceptance of digital artefacts, through the specific case study of robotic vacuum cleaners in domestic environments. It aims to enhance the existing body of knowledge by examining these factors in depth, focusing on the concept of composite affordance within the Technology Acceptance Model (TAM). This approach offers a more nuanced perspective on technology adoption, which can inform a more user-centric design and development of artefacts, thereby enhancing their usability and acceptance.

As mentioned, the selected case study for the present thesis is represented by the digital transformation of robotic vacuum cleaners. Designing effective robotic vacuum cleaners involves focusing on enhancing various affordances to improve user experience and satisfaction.

From the literature, various design suggestions have been identified but the validation of the proposed model will be left to future studies using the questionnaire designed specifically for this case study.

Cognitive affordances play an important role in making controls and interfaces simple and easy to understand. Designers should aim to ensure that labels are clear, and functions are predictable. Providing immediate and clear feedback for user actions can help users understand the system's status and responses, which may reduce the learning curve and enhance overall usability.

Physical affordances consider the size, shape, and placement of the device to make it easy to handle, set up, and maintain. Interfaces and controls should be designed to require minimal physical effort, reducing the need for repetitive actions. This could help make the device convenient and comfortable to use, accommodating a wide range of users, including those with physical limitations.

Functional affordances involve making sure that all features of the robotic vacuum cleaner are accessible and customisable to meet different user needs. Frequently used functions should be easily accessible, allowing users to quickly and efficiently operate the device. Features such as efficient navigation patterns and thorough cleaning capabilities could help users achieve their cleaning goals effectively, making the device more practical and appealing.

Sensory affordances focus on incorporating clear visual elements and multisensory feedback. Designers should use distinguishable icons, buttons, and texts that stand out from the background and are easy to identify. Providing visual, auditory, and tactile feedback can cater to different user preferences and enhance the overall experience. This multisensory approach may help ensure that users receive the necessary cues and confirmations during operation.

To foster users' adoption and satisfaction, designers could also offer customisation options that allow users to personalise their experience according to their specific needs and preferences. Providing robust customer support, detailed user manuals, and tutorials can assist users in getting the most out of their devices and address any issues they may encounter, further enhancing satisfaction and encouraging positive word-of-mouth.

Designers should also consider emotional affordances at visceral, behavioural, and reflective levels.

The visceral level refers to the user's instant emotional response to a product's look and sensory appeal. Design elements could elicit an immediate positive reaction through thoughtful use of colours, shapes, textures, and sounds. Using colour psychology to evoke specific emotions, choosing materials that are pleasant to touch, and incorporating pleasant auditory cues, such as a satisfying click of a button, might enhance the overall sensory experience.

The behavioural level focuses on how users interact with the product. Designers should aim to create a product that is intuitive and user-friendly, providing clear feedback on user actions. Conducting extensive usability testing can help identify and rectify pain points in the user experience. Developing clear, straightforward interaction paths that minimise cognitive load and enhance user control could help users build familiarity and confidence in using the product.

The reflective level involves the user's deeper cognitive processes, including the personal significance and long-term impact of the product. Designers might focus on creating products that resonate with users' values, aspirations, and identities. Providing personalisation options that enable users to customise the product could increase emotional investment. Communicating the brand’s values and mission through the product may promote a sense of belonging and trust.

By focusing on these aspects, designers could create robotic vacuum cleaners that are more user-friendly, efficient, and appealing, meeting user needs and encouraging widespread adoption. These statements are proposed based on analysed literature but will need to be tested using the questionnaire created specifically for this purpose.

In conclusion, this research aims to advance our understanding of technology adoption dynamics, particularly concerning robotic vacuum cleaners. By employing rigorous methodologies and innovative theoretical frameworks, the study seeks to make meaningful contributions to both academic scholarship and practical applications in the field of consumer technology adoption.

Appendix A

Sezione 1: Informazioni di base sui partecipanti

Informazioni generali:

1. Genere:

    - Maschio
    - Femmina
    - Preferisco non specificare

2. Età:

    - Meno di 30
    - 31-40
    - 41-50
    - Piu di 50

Informazioni personali:

3. Tipo di lavoro

    - Studente
    - Lavoratore dipendente
    - Lavoratore autonomo
    - Disoccupato
    - Casalinga/o
    - Pensionato

4. Ritieni di avere una buona familiarità con la tecnologia?

    - Fortemente in disaccordo
    - In disaccordo
    - Né d'accordo né in disaccordo
    - D'accordo
    - Fortemente d'accordo

5. Indica la tua fascia di reddito

- Fino a 15000
- Da 15001 a 28000
- Da 28001 a 50000
- Oltre 50000
- Preferisco non specificare

Sezione 2: Possesso dell'aspirapolvere

6. Possiedi un’aspirapolvere?

    - Si
    - No

7. Che tipo di aspirapolvere possiedi?

    Elenco a scelta multipla con foto per maggiore chiarezza

    - Aspirapolvere a tanica
    - Aspirapolvere a tanica senza sacco
    - Aspirapolvere verticale con sacco
    - Aspirapolvere verticale senza sacco
    - Aspirapolvere stick con filo
    - Aspirapolvere stick senza filo
    - Aspirapolvere robot

8. Hai mai sentito parlare di aspirapolveri robot?

    - Si
    - No

9. Possiedi un’aspirapolvere robot?

    - Si
    - No

10. Per quale dei seguenti motivi hai acquistato o hai intenzione di acquistare un’aspirapolvere robot?

Elenco a scelta multipla

- Risparmiare tempo
- Risparmiare energia
- Risparmiare denaro
- Garantire il comfort e rendere le cose più facili
- Offrire tranquillità
- Migliorare la qualità della vita
- Migliorare la salute
- Per compagnia
- Il mio interesse generale per la tecnologia più recente
- Impressionare i miei amici e la mia famiglia
- Altro (specificare)
- Nessun motivo.

11. Se non possiedi dispositivi un'aspirapolvere robot, indica per quale motivo

Elenco a scelta multipla

- Costo
- Privacy e sicurezza
- Incertezza sull'efficacia/benefici
- Scarsa familiarità con il dispositivo
- Altro (specifica)

12. Se non possiedi, sei interessato al loro acquisto?

- Si
- No

13. Quali sono le tue maggiori preoccupazioni verso i dispositivi smart come le aspirapolveri robot?

Elenco a scelta multipla

- Sicurezza e privacy
- Affidabilità della tecnologia

- Praticità
- Costo
- Facilità di utilizzo/manutenzione
- Altro (specifica)

TAM e Affordance

Valuta le seguenti affermazioni su una scala Likert a sette livelli.

14. Perceived Usefulness:

- L'utilizzo dell’aspirapolvere robot aumenta l'efficacia delle pulizie.
- L'utilizzo dell’aspirapolvere robot mi fa risparmiare tempo e fatica nello svolgimento delle faccende domestiche.
- L'utilizzo dell’aspirapolvere robot migliora la qualità della vita.
- L'utilizzo dell’aspirapolvere robot mi permetterebbe di svolgere più facilmente le attività domestiche.
- Nel complesso, ritengo che l'uso dell’aspirapolvere robot sia vantaggioso e utile per me.

15. Perceived Ease of Use:

- L’utilizzo del dispositivo è facile.
- Imparare ad usare le aspirapolveri robot è facile per me.
- Utilizzo l’aspirapolvere robot non richiede molta concentrazione.
- L'interazione con il dispositivo è chiara e comprensibile.
- È facile far fare al dispositivo ciò che voglio.

16. Attitude to use:

- L'utilizzo dell’aspirapolvere robot è una buona idea.
- Utilizzare l’aspirapolvere robot è vantaggioso per me.
- Mi piace l'idea di utilizzare l’aspirapolvere robot.

17. Intention to use:

- Intendo utilizzare l’aspirapolvere robot in futuro

- Consiglierei l’aspirapolvere robot ad altri.
- Intendo acquistare l’aspirapolvere robot in futuro.

18. Cognitive Affordance:

- L’aspetto del dispositivo è semplice e presenta pochi pulsanti per le funzioni principali.
- Il nome dei pulsanti e dei menù sono esplicativi riguardo la funzione.
- Le informazioni chiave vengono fornite in modo chiaro e conciso.
- Le icone ed i testi sono facilmente comprensibili.

19. Physical Affordance:

- Il dispositivo prevede diverse modalità di funzionamento.
- Il dispositivo è facilmente controllabile.
- Il dispositivo è maneggevole.
- I pulsanti sono facilmente visibili e raggiungibili.

20. Functional Affordance:

- Sono predisposti pulsanti di scelta rapida per le funzioni più utilizzate.
- Le impostazioni del dispositivo sono personalizzabili.
- Il dispositivo fornisce un riscontro immediato sull'azione dell'utente.
- Il dispositivo è progettato per minimizzare i rischi e gli errori.

21. Sensory Affordance:

- Vengono utilizzati testi di facile lettura.
- Vi è contrasto tra il colore dei pulsanti e il colore del dispositivo.
- Vengo enfatizzati gli elementi importanti o che necessitano di attenzione.
- Il dispositivo fornisce informazioni adeguatamente.

23. Emotional Affordance:

Visceral level

- L'interfaccia del prodotto è progettata in modo estetico.
- Il complessivo aspetto dell'aspirapolvere robot è visivamente accattivante.

Behavioural level

- L'aspirapolvere robot abbia una semplice interfaccia di navigazione.
- Penso che il dispositivo sia facile da configurare.
- Ritengo sia facile far fare all'aspirapolvere robot ciò che voglio.

Reflective level

- Grazie all'aspirapolvere robot la mia casa è sempre pulita.
- L'aspirapolvere robot è in grado di aspirare tutti i tipi di detriti.
- Il dispositivo è in grado di raggiungere gli angoli e gli spazi più stretti.

Bibliography

A. Shuhaiber, I. Mashal, and O. Alsaryrah. 2019. 'The Role of Smart Homes' Attributes on Users' Acceptance'. In *2019 International Conference on Electrical and Computing Technologies and Applications (ICECTA)*, 1–4. https://doi.org/10.1109/ICECTA48151.2019.8959592.

Agarwal, Ritu, and Jayesh Prasad. 2007. 'The Role of Innovation Characteristics and Perceived Voluntariness in the Acceptance of Information Technologies'. *Decision Sciences* 28 (June):557–82. https://doi.org/10.1111/j.1540-5915.1997.tb01322.x.

Altshuller, G.S. 1999. *The Innovation Algorithm: TRIZ, Systematic Innovation and Technical Creativity*.

Ana Valencia, Ruth Mugge, Jan Schoormans, and Hendrik Schifferstein. 2015. 'The Design of Smart Product-Service Systems (PSSs): An Exploration of Design Characteristics'. *International Journal of Design; Vol 9, No 1 (2015)*. https://www.ijdesign.org/index.php/IJDesign/article/view/1740/677.

Anderson, Philip, and Michael Tushman. 1990. 'Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change'. *Administrative Science Quarterly* 35 (December). https://doi.org/10.2307/2393511.

Aykut Coskun, Gül Kaner, and İdil Bostan. 2018. 'Is Smart Home a Necessity or a Fantasy for the Mainstream User? A Study on Users' Expectations of Smart Household Appliances'. *International Journal of Design; Vol 12, No 1 (2018)*. https://www.ijdesign.org/index.php/IJDesign/article/view/2938.

Baheti, R., and H. Gill. 2011. 'Cyber-Physical Systems'. *Impact Control Technol* 12 (January):1–6.

Bareither, Christoph. 2019. 'Doing Emotion through Digital Media An Ethnographic Perspective on Media Practices and Emotional Affordances'. *Ethnologia Europaea* 49 (February). https://doi.org/10.16995/ee.822.

Bernsdorf, Christopher, Nathalie Hasreiter, Daniel Kranz, Sven Sommer, and Alexander Rossmann. 2016. *Technology Acceptance in the Case of IoT Appliances*.

Bevan, Nigel, and Miles Macleod. 1994. 'Usability Measurement in Context'. *Behaviour and Information Technology* 13 (January):132–45. https://doi.org/10.1080/01449299408914592.

Blair-Early, Adream, and Mike Zender. 2008. 'User Interface Design Principles for Interaction Design'. *Design Issues* 24 (July):85–107. https://doi.org/10.1162/desi.2008.24.3.85.

Blau, P. M. 1964. *Exchange and Power in Social Life*. J. Wiley. https://books.google.it/books?id=1mtqAAAAMAAJ.

Boksberger, Philipp, and Lisa Melsen. 2011. 'Perceived Value: A Critical Examination of Definitions, Concepts and Measures for the Service Industry'. *Journal of Services Marketing* 25 (May):229–40. https://doi.org/10.1108/08876041111129209.

Cantamessa, Marco, Francesca Montagna, Stefania Altavilla, and Alessandro Casagrande-Seretti. 2020. 'Data-Driven Design: The New Challenges of Digitalization on Product Design and Development'. *Design Science* 6:e27. https://doi.org/10.1017/dsj.2020.25.

Carter, J. Adam, Emma C. Gordon, and S. Orestis Palermos. 2016. 'Extended Emotion'. *Philosophical Psychology* 29 (2): 198–217.

Cerniauskaite, Guoda, Jolanta Sabaitytė, and Edita Leonavičienė. 2020. 'Use of Generational Theory for the Assessment of Involvement In International Electronic Commerce Activities'. *Challenges to National Defence in Cotemporary Geopolitical Situation* 2020 (October):272–81. https://doi.org/10.47459/cndcgs.2020.36.

Chemero, Anthony. 2003. 'An Outline of a Theory of Affordances'. *Ecological Psychology* 15 (April). https://doi.org/10.1207/S15326969ECO1502_5.

Chen, Chenyi, Ari Seff, Alain Kornhauser, and Jianxiong Xiao. 2015. *DeepDriving: Learning Affordance for Direct Perception in Autonomous Driving*. https://doi.org/10.1109/ICCV.2015.312.

Cho, Younjoo, and Anseop Choi. 2020. 'Application of Affordance Factors for User-Centered Smart Homes: A Case Study Approach'. *Sustainability* 12 (7): 3053. https://doi.org/10.3390/su12073053.

Christensen, Clayton M. 1997. 'The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail'. *MA:Harvard Business School Press*.

Christensen, Henrik. 2001. *Intelligent Home Appliances*. *International Journal of Robotic Research - IJRR*. Vol. 6. https://doi.org/10.1007/3-540-36460-9_21.

Clark, Kim B. 1985. 'The Interaction of Design Hierarchies and Market Concepts in Technological Evolution'. *Research Policy* 14 (5): 235–51. https://doi.org/10.1016/0048-7333(85)90007-1.

Colombo, S., F. Montagna, G. Cascini, and V. F. Palazzolo. 2022. 'Digital Artefacts and The Role of Digital Affordance'. *Proceedings of the Design Society* 2 (May):11–20. https://doi.org/10.1017/pds.2022.2.

Dario, Paolo, Eugenio Guglielmelli, and Cecilia Laschi. 2001. 'Humanoids and Personal Robots: Design and Experiments'. *Journal of Robotic Systems* 18 (December):673–90. https://doi.org/10.1002/rob.8106.

Davis, Fred D. 1989. 'Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology'. *MIS Quarterly* 13 (3): 319–40. https://doi.org/10.2307/249008.

Davis, Fred D., Richard P. Bagozzi, and Paul R. Warshaw. 1989. 'User Acceptance of Computer Technology: A Comparison of Two Theoretical Models'. *Management Science* 35 (8): 982–1003.

Davis, Jenny L., and James B. Chouinard. 2016. 'Theorizing Affordances: From Request to Refuse'. *Bulletin of Science, Technology & Society* 36 (4): 241–48.

Desmet, Pieter. 2002. 'Designing Emotions'.

Dutton, John M., and Annie Thomas. 1984. 'Treating Progress Functions as a Managerial Opportunity'. *The Academy of Management Review* 9 (2): 235–47. https://doi.org/10.2307/258437.

E. Park, Y. Cho, J. Han, and S. J. Kwon. 2017. 'Comprehensive Approaches to User Acceptance of Internet of Things in a Smart Home Environment'. *IEEE Internet of Things Journal* 4 (6): 2342–50. https://doi.org/10.1109/JIOT.2017.2750765.

Edwards, W., and Rebecca Grinter. 2001. *At Home with Ubiquitous Computing: Seven Challenges*. Vol. 256. https://doi.org/10.1007/3-540-45427-6_22.

Evans, Sandra K., Katy E. Pearce, Jessica Vitak, and Jeffrey W. Treem. 2017. 'Explicating Affordances: A Conceptual Framework for Understanding Affordances in Communication Research: EXPLICATING AFFORDANCES'. *Journal of Computer-Mediated Communication* 22 (1): 35–52. https://doi.org/10.1111/jcc4.12180.

Ezer, Neta, Arthur Fisk, and Wendy Rogers. 2009. *Attitudinal and Intentional Acceptance of Domestic Robots by Younger and Older Adults*. Vol. 5615. https://doi.org/10.1007/978-3-642-02710-9_5.

Fink, Julia, Valérie Bauwens, Frédéric Kaplan, and Pierre Dillenbourg. 2013. 'Living with a Vacuum Cleaning Robot: A 6-Month Ethnographic Study'. *International Journal of Social Robotics* 5 (3): 389–408. https://doi.org/10.1007/s12369-013-0190-2.

Fishbein, M., and Icek Ajzen. 1975. *Belief, Attitude, Intention and Behaviour: An Introduction to Theory and Research*. Vol. 27.

Forlizzi, Jodi. 2007. *How Robotic Products Become Social Products: An Ethnographic Study of Cleaning in the Home*. *HRI 2007 - Proceedings of the 2007 ACM/IEEE Conference on Human-Robot Interaction - Robot as Team Member*. https://doi.org/10.1145/1228716.1228734.

Forlizzi, Jodi, and Carl Disalvo. 2006. *Service Robots in the Domestic Environment: A Study of the Roomba Vacuum in the Home*. Vol. 2006. https://doi.org/10.1145/1121241.1121286.

Gaver, William. 1991. *Technology Affordances*. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/108844.108856.

Gaver. 1992. 'The Affordances of Media Spaces for Collaboration', January. https://doi.org/10.1145/143457.371596.

Ghafurian, Moojan, Colin Ellard, and Kerstin Dautenhahn. 2023. 'An Investigation into the Use of Smart Home Devices, User Preferences, and Impact during COVID-19'. *Computers in Human Behavior Reports* 11 (August):100300. https://doi.org/10.1016/j.chbr.2023.100300.

Gibson, J. J. 1977. *The Ecological Approach to Visual Perception*. Lawrence Erlbaum Associates. https://books.google.it/books?id=DrhCCWmJpWUC.

Goedkoop, Mark. 1999. 'Product Service Systems'. *Ecological and Economic Basis*.

Guttman, L. 1944. 'A Basis for Scaling Qualitative Data'. *American Sociological Review* 20 (January):139–50. https://doi.org/10.2307/2086306.

Ha, Sejin, and Leslie Stoel. 2009. 'Consumer E-Shopping Acceptance: Antecedents in a Technology Acceptance Model'. *Current Issues in Retailing: Relationships and Emerging Opportunities* 62 (5): 565–71. https://doi.org/10.1016/j.jbusres.2008.06.016.

Hammond, Michael. 2010. 'What Is an Affordance and Can It Help Us Understand the Use of ICT in Education? Education and Information Technologies, 15(3), 205-217'. *Education and Information Technologies* 15 (September):205–17. https://doi.org/10.1007/s10639-009-9106-z.

Hartson, Rex. 2003. 'Cognitive, Physical, Sensory, and Functional Affordances in Interaction Design'. *Behaviour & Information Technology* 22 (5): 315–38. https://doi.org/10.1080/01449290310001592587.

Hartwick, Jon, and Henri Barki. 1994. 'Explaining the Role of User Participation in Information System Use'. *Management Science* 40 (4): 440–65.

Hatfield, Elaine, John T. Cacioppo, and Richard L. Rapson. 1993. *Emotional Contagion*. Studies in Emotion and Social Interaction. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139174138.

Henderson, Rebecca, and Kim Clark. 1990. 'Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms'. *Administrative Science Quarterly* 35 (March). https://doi.org/10.2307/2393549.

Hill, T. P. 1977. 'ON GOODS AND SERVICES'. *Review of Income and Wealth* 23 (4): 315–38. https://doi.org/10.1111/j.1475-4991.1977.tb00021.x.

Holden, Richard J., and Ben-Tzion Karsh. 2010. 'The Technology Acceptance Model: Its Past and Its Future in Health Care'. *Journal of Biomedical Informatics* 43 (1): 159–72. https://doi.org/10.1016/j.jbi.2009.07.002.

J. Stragier, L. Hauttekeete, and L. De Marez. 2010. 'Introducing Smart Grids in Residential Contexts: Consumers' Perception of Smart Household Appliances'. In *2010 IEEE Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply*, 135–42. https://doi.org/10.1109/CITRES.2010.5619864.

Jackson, Ralph W., Lester A. Neidell, and Dale A. Lunsford. 1995. 'An Empirical Investigation of the Differences in Goods and Services as Perceived by Organizational Buyers'. *Industrial Marketing Management* 24 (2): 99–108. https://doi.org/10.1016/0019-8501(94)00037-W.

Jensen, Thomas, and Sarah Bro Trasmundi. 2016. 'Affect and Affordances – The Role of Action and Emotion in Social Interaction'. *Cognitive Semiotics* 9 (May). https://doi.org/10.1515/cogsem-2016-0003.

Jia, Jia, Hong Tang, Chong Lei, and Chunrong Pu. 2023. 'Research on Consumer Preferences and Potential Users of Vacuum Cleaning Robots-Based on Text Mining and Questionnaire Surveys'. In . https://doi.org/10.3233/ATDE231002.

Joo, Jihyuk, and Yoonmo Sang. 2013. 'Exploring Koreans' Smartphone Usage: An Integrated Model of the Technology Acceptance Model and Uses and Gratifications Theory'. *Computers in Human Behavior* 29 (6): 2512–18. https://doi.org/10.1016/j.chb.2013.06.002.

Jordan, P. W. 2002. *Designing Pleasurable Products: An Introduction to the New Human Factors*. Taylor & Francis. https://books.google.it/books?id=0s3el8sDjHsC.

Jung, Heekyoung, and Erik Stolterman. 2011. 'Form and Materiality in Interaction Design: A New Approach to HCI'. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems*, 399–408. Vancouver BC Canada: ACM. https://doi.org/10.1145/1979742.1979619.

Kalantari, Mahdokht. 2017. 'Consumers' Adoption of Wearable Technologies: Literature Review, Synthesis, and Future Research Agenda'. *International Journal of Technology Marketing* 12 (January):274. https://doi.org/10.1504/IJTMKT.2017.089665.

Kallinikos, Jannis, Aleksi Aaltonen, and Attila Marton. 2010. 'A Theory of Digital Objects'. *First Monday*, June. https://doi.org/10.5210/fm.v15i6.3033.

Khanna, Shivansh, and Shraddha Srivastava. 2022. 'Human-Robot Collaboration in Cleaning Applications: Methods, Limitations, and Proposed Solutions'. *Eigenpub Review of Science and Technology* 6 (1): 52–74.

KIESLER, C. A. K. S. B. 1969. *Conformity*. https://books.google.it/books?id=ghq_D8AnIYIC.

Kim, Hee-Woong, Hock Chan, and Sumeet Gupta. 2007. 'Value-Based Adoption of Mobile Internet: An Empirical Investigation'. *Decision Support Systems* 43 (February):111–26. https://doi.org/10.1016/j.dss.2005.05.009.

Kotler, P., G. Armstrong, L. Brown, and S. Adam. 2007. *Marketing*. 7th ed. Pearson Education Australia.

Krägeloh, Christian U., Jaishankar Bharatharaj, Senthil K. Sasthan Kutty, Praveen R. Nirmala, and Loulin Huang. 2019. 'Questionnaires to Measure Acceptability of Social Robots: A Critical Review'. *Robotics* 8 (4). https://doi.org/10.3390/robotics8040088.

Kyttä, Marketta. 2003. 'Children in Outdoor Contexts. Affordances and Independent Mobility in the Assessment of Environmental Child Friendliness'. *951-22-6858-2*, January.

Lee, Edward. 2015. 'The Past, Present and Future of Cyber-Physical Systems: A Focus on Models'. *Sensors (Basel, Switzerland)* 15 (March):4837–69. https://doi.org/10.3390/s150304837.

Lee, Ya-Ching. 2008. 'The Role of Perceived Resources in Online Learning Adoption'. *Computers & Education* 50 (May):1423–38. https://doi.org/10.1016/j.compedu.2007.01.001.

Leonardi, Paul. 2013. 'Theoretical Foundations for the Study of Sociomateriality'. *Information and Organization* 23 (February). https://doi.org/10.1016/j.infoandorg.2013.02.002.

Lin, Tung-Ching, Sheng Wu, Jack Hsu, and Yi-Ching Chou. 2012. 'The Integration of Value-Based Adoption and Expectation–Confirmation Models: An Example of IPTV Continuance Intention'. *Decision Support Systems* 54 (December):63–75. https://doi.org/10.1016/j.dss.2012.04.004.

Linjawi, Manal, and Roger Moore. 2018. *Towards a Comprehensive Taxonomy for Characterizing Robots*.

Liu, An-Chi, and Tsung-Yu Chou. 2020. 'AN INTEGRATED TECHNOLOGY ACCEPTANCE MODEL TO APPROACH THE BEHAVIORAL INTENTION OF SMART HOME APPLIANCE.' *International Journal of Organizational Innovation* 13 (2): 95.

Lovelock, Christopher, and Evert Gummesson. 2004. 'Whither Services Marketing?: In Search of a New Paradigm and Fresh Perspectives'. *Journal of Service Research* 7 (1): 20–41. https://doi.org/10.1177/1094670504266131.

Maier, Jonathan, and Georges Fadel. 2009. 'Affordance Based Design: A Relational Theory for Design'. *Res. Eng. Des.* 20 (March):13–27. https://doi.org/10.1007/s00163-008-0060-3.

Mandel, Theo. 1997. *The Elements of User Interface Design*.

Masoudi, Nafiseh, Georges M. Fadel, Christopher C. Pagano, and Maria Vittoria Elena. 2019. 'A Review of Affordances and Affordance-Based Design to Address Usability'.

Proceedings of the Design Society: International Conference on Engineering Design 1 (1): 1353–62. https://doi.org/10.1017/dsi.2019.141.
Mcgrenere, Joanna, and Wayne Ho. 2000. *Affordances: Clarifying and Evolving a Concep. Proceedings of the Graphics Interface 2000 Conference*.
Mert, Wilma. 2008. 'Consumer Acceptance of Smart Appliances'. D 5.5 of WP 5. Smart Domestic Appliances in Sustainable Energy Systems (Smart-A). European Commission. https://ifz.at/sites/default/files/2021-02/D5_5-Consumer%20acceptance.pdf.
Montagna, Francesca. 2024. 'Product Planning: Understanding the Market and Positioning Products'. Politecnico di Torino.
Monti, Teresa, Samuele Colombo, Francesca Montagna, and Gaetano Cascini. 2024. 'The Relation between Service and Digital Transition: Implications for Designers'. *Proceedings of the Design Society* 4 (May):315–24. https://doi.org/10.1017/pds.2024.34.
Moore, Gary C., and Izak Benbasat. 1991. 'Development of an Instrument to Measure the Perceptions of Adopting an Information Technology Innovation'. *Inf. Syst. Res.* 2:192–222.
Morie, Jacquelyn, Josh Williams, Aimee Dozois, and Donat-Pierre Luigi. 2005. 'The Fidelity of "Feel": Emotional Affordance in Virtual Environments', July, 11.
MORRIS, MICHAEL, and Viswanath Venkatesh. 2000. 'Age Differences in Technology Adoption Decisions: Implications for a Changing Work Force'. *Personnel Psychology* 53 (June):375–403. https://doi.org/10.1111/j.1744-6570.2000.tb00206.x.
'Nielsen, J. 10 Usability Heuristics for User Interface Design. Nielsen Norman Group, 24 April 1994'. n.d. https://www.nngroup.com/articles/ten-usability-heuristics/.
Norman, D. 1988. *The Psycology of Everyday Things*. New Tork: Basic Books.
Norman, D. A. 2013. *The Design of Everyday Things*. MIT Press. https://books.google.it/books?id=heCtnQEACAAJ.
Norman, D., and S.W. Draper. 1986. *User-Centered System Design: New Perspectives on Human- Computer Interaction.*
Norman, Donald. 2004. 'Emotional Design: Why We Love (or Hate) Everyday Things'. In *The Journal of American Culture*. Vol. 27.
Oxman, Rivka. 2006. 'Theory and Design in the First Digital Age'. *Design Studies* 27 (May). https://doi.org/10.1016/j.destud.2005.11.002.
Palmstedt, Paul. 2013. 'Electrolux Global Vacuuming Survey 2013 Report'. Electrolux. https://www.electroluxgroup.com/wp-content/uploads/sites/2/2013/10/Electrolux-Global-Vacuuming-Survey-2013-Full-report.pdf.
Parchoma, Gale. 2014. 'The Contested Ontology of Affordances: Implications for Researching Technological Affordances for Collaborative Knowledge Production'. *Computers in Human Behavior* 37 (August):360–68. https://doi.org/10.1016/j.chb.2012.05.028.
Park, Taejung, and Cheolil Lim. 2018. 'Design Principles for Improving Emotional Affordances in an Online Learning Environment'. *Asia Pacific Education Review* 20 (November). https://doi.org/10.1007/s12564-018-9560-7.
Park, Yangil, and Jengchung Chen. 2007. 'Acceptance and Adoption of the Innovative Use of Smartphone'. *Industrial Management and Data Systems* 107 (November):1349–65. https://doi.org/10.1108/02635570710834009.
Perpignano, E. 2020. 'L'affordance Negli Artefatti Digitali: Un'analisi Sui Servizi'. Politecnico di Torino.
Persico, Donatella, Stefania Manca, and Francesca Pozzi. 2014. 'Adapting the Technology Acceptance Model to Evaluate the Innovative Potential of E-Learning Systems'. *Computers in Human Behavior* 30 (January):614–22. https://doi.org/10.1016/j.chb.2013.07.045.
Pfeffer, J. 1982. *Organizations and Organization Theory*. Pitman. https://books.google.it/books?id=xVm3AAAAIAAJ.

Pucillo, Francesco, and Gaetano Cascini. 2014. ‘A Framework for User Experience, Needs and Affordances’. *Design Studies* 35 (2): 160–79. https://doi.org/10.1016/j.destud.2013.10.001.

Quah, Danny. 2003. ‘Digital Goods and the New Economy’, April.

Radu, S. 2015. ‘Relation between Function and Form in Vacuum Clenaers Design’. *Journal of Industrial Design and Engineering Graphics* 10 (2): 37–42.

Rayna, Thierry. 2008. ‘Understanding the Challenges of the Digital Economy: The Nature of Digital Goods’. *Communications & Strategies* 1 (January):13–36.

‘Robotic Vacuum Cleaner Market Share Worldwide from 2014 to 2020, by Brand’. 2024. *Statista*, August. https://www-statista-com.ezproxy.biblio.polito.it/statistics/934089/worldwide-robotic-vacuum-cleaner-market-share/.

Rogers, Everett M. 1995. ‘Diffusion of Innovations: Modifications of a Model for Telecommunications’. In *Die Diffusion von Innovationen in Der Telekommunikation*, edited by Matthias-W. Stoetzer and Alwin Mahler, 25–38. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-79868-9_2.

Roskos, Kathleen, Jeremy Brueck, and Lisa Lenhart. 2017. ‘An Analysis of E-Book Learning Platforms: Affordances, Architecture, Functionality and Analytics’. *International Journal of Child-Computer Interaction* 12 (January). https://doi.org/10.1016/j.ijcci.2017.01.003.

Sadeck, Osman. 2022. ‘Technology Adoption Model: Is Use/Non-Use a Case of Technological Affordances or Psychological Disposition or Pedagogical Reasoning in the Context of Teaching During the COVID-19 Pandemic Period?’ *Frontiers in Education* 7 (July):906195. https://doi.org/10.3389/feduc.2022.906195.

Sanders, Elizabeth. 2010. ‘Converging Perspectives: Product Development Research for the 1990s’. *Design Management Journal (Former Series)* 3 (June):49–54. https://doi.org/10.1111/j.1948-7169.1992.tb00604.x.

Sandström, Sara, Bo Edvardsson, Per Kristensson, and Peter Magnusson. 2008. ‘Value in Use through Service Experience’. *Managing Service Quality* 18 (March). https://doi.org/10.1108/09604520810859184.

Sanna, C. 2022. ‘L’AFFORDANCE DIGITALE IN SISTEMI BIM-BASED: CERCANDO DI COLMARE IL GAP TRA SVILUPPATORI E UTENTI DI ARTEFATTI DIGITALI.’ Politecnico di Torino.

Seet, Boon-Chong, and Tiong-Thye Goh. 2012. ‘Exploring the Affordance and Acceptance of an E-reader Device as a Collaborative Learning System’. *The Electronic Library* 30 (4): 516–42. https://doi.org/10.1108/02640471211252229.

Shachak, Aviv, Craig Kuziemsky, and Carolyn Petersen. 2019. ‘Beyond TAM and UTAUT: Future Directions for HIT Implementation Research’. *Journal of Biomedical Informatics* 100 (December):103315. https://doi.org/10.1016/j.jbi.2019.103315.

Shih, Hung-Pin. 2004. ‘An Empirical Study on Predicting User Acceptance of E-Shopping on the Web’. *Information & Management* 41 (January):351–68. https://doi.org/10.1016/S0378-7206(03)00079-X.

Shuhaiber, Ahmed, and Ibrahim Mashal. 2019. ‘Understanding Users’ Acceptance of Smart Homes’. *Technology in Society* 58 (August):101110. https://doi.org/10.1016/j.techsoc.2019.01.003.

Steinert, Steffen, and Matthew James Dennis. 2022. ‘Emotions and Digital Well-Being: On Social Media’s Emotional Affordances’. *Philosophy & Technology* 35 (2): 36. https://doi.org/10.1007/s13347-022-00530-6.

Sung, Ja-Young, Rebecca Grinter, Henrik Christensen, and Lan Guo. 2008. ‘Housewives or Technophiles?: Understanding Domestic Robot Owners’. *HRI 2008 - Proceedings of the 3rd ACM/IEEE International Conference on Human-Robot Interaction: Living with Robots*, March. https://doi.org/10.1145/1349822.1349840.

Sung, JaYoung, Rebecca E. Grinter, and Henrik I. Christensen. 2010. ‘Domestic Robot Ecology: An Initial Framework to Unpack Long-Term Acceptance of Robots at

Home'. *International Journal of Social Robotics* 2 (4): 417–29. https://doi.org/10.1007/s12369-010-0065-8.

Suschek-Berger, Jurgen. 2008. 'Evaluation Report Consumer Survey on Smart Appliances'. D 5.2 of WP 5.2. Smart Domestic Appliances in Sustainable Energy Systems (Smart-A). European Communities. https://ifz.at/sites/default/files/2021-02/Consumer%20survey%20on%20smart%20appliances_0.pdf.

Tiger, L. 1992. *The Pursuit of Pleasure*. Little, Brown. https://books.google.it/books?id=sLKtQgAACAAJ.

Tiotto, Elena. 2022. 'Analisi Dei Requisiti Di Un Sistema Digitale e Delle Interazioni Tra Questo e l'utente'. Politecnico di Torino.

Turhan, Gülden. 2013. 'An Assessment towards the Acceptance of Wearable Technology to Consumers in Turkey: The Application to Smart Bra and t-Shirt Products'. *The Journal of The Textile Institute* 104 (4): 375–95. https://doi.org/10.1080/00405000.2012.736191.

Ulrich, Karl. 1995. 'The Role of Product Architecture in the Manufacturing Firm'. *Research Policy* 24 (3): 419–40. https://doi.org/10.1016/0048-7333(94)00775-3.

Utterback, M., and W.J. Abernathy. 1975. 'A Dynamic Model of Process and Product Innovation. OMEGA'. *Int. J. Manage. Sci.* 5 (January):639–56.

Vallverdu, Jordi, and Gabriele Trovato. 2016. 'Emotional Affordances for Human–Robot Interaction'. *Adaptive Behavior* 24 (October). https://doi.org/10.1177/1059712316668238.

Van Gorp, Trevor, and Edie Adams. 2012. *Design for Emotion*. https://doi.org/10.1016/C2010-0-67661-9.

Venkatesh, Viswanath, and Fred Davis. 2000. 'A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies'. *Management Science* 46 (February):186–204. https://doi.org/10.1287/mnsc.46.2.186.11926.

Venkatesh, Viswanath, Michael G. Morris, Gordon B. Davis, and Fred D. Davis. 2003. 'User Acceptance of Information Technology: Toward a Unified View'. *MIS Quarterly* 27 (3): 425–78. https://doi.org/10.2307/30036540.

Venkatesh, Viswanath, James Thong, and Xin Xu. 2012. 'Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology'. *MIS Quarterly* 36 (March):157–78. https://doi.org/10.2307/41410412.

Vijayasarathy, Leo R. 2004. 'Predicting Consumer Intentions to Use On-Line Shopping: The Case for an Augmented Technology Acceptance Model'. *Information & Management* 41 (6): 747–62. https://doi.org/10.1016/j.im.2003.08.011.

Vitali, Ilaria, Venanzio Arquilla, and Umberto Tolino. 2017. 'A Design Perspective for IoT Products. A Case Study of the Design of a Smart Product and a Smart Company Following a Crowdfunding Campaign'. *The Design Journal* 20 (sup1): S2592–2604. https://doi.org/10.1080/14606925.2017.1352770.

Wickramasinghe, Chathurangi Ishara, and Delphine Reinhardt. 2020. 'A Survey-Based Exploration of Users' Awareness and Their Willingness to Protect Their Data with Smart Objects'. In *Privacy and Identity Management. Data for Better Living: AI and Privacy: 14th IFIP WG 9.2, 9.6/11.7, 11.6/SIG 9.2.2 International Summer School, Windisch, Switzerland, August 19–23, 2019, Revised Selected Papers*, edited by Michael Friedewald, Melek Önen, Eva Lievens, Stephan Krenn, and Samuel Fricker, 427–46. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-42504-3_27.

Wu, Chih-Fu, Ying-Kit Wong, Hsiu-Hui Hsu, and Cheng-Yu Huang. 2022. 'Applying Affordance Factor Analysis for Smart Home Speakers in Different Age Groups: A Case Study Approach'. *Sustainability* 14 (4). https://doi.org/10.3390/su14042156.

Y. Yang, X. Yu, Z. Zhang, and L. Gan. 2023. 'Integrating Technology Acceptance Model With Maslow's Hierarchy Needs Theory to Investigate Smart Homes Adoption'. *IEEE Access* 11:80726–40. https://doi.org/10.1109/ACCESS.2023.3300724.

Yapici, Nur Beril. 2022. 'The Effect of Human-Robot Interaction on Design and Use Process of Home Robots'. Izmir Institute of Technology. https://hdl.handle.net/11147/12467.

Yoo, Youngjin, Richard Boland, Kalle Lyytinen, and Ann Majchrzak. 2012. 'Organizing for Innovation in the Digitized World'. *Organization Science* 23 (September):1398–1408. https://doi.org/10.1287/orsc.1120.0771.

Yoo, Youngjin, Ola Henfridsson, and Kalle Lyytinen. 2010. 'Research Commentary: The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research'. *Information Systems Research* 21 (4): 724–35.

Yu, Ying, and Tung-Jung Sung. 2023. 'A Value-Based View of the Smart PSS Adoption: A Study of Smart Kitchen Appliances'. *Service Business* 17 (2): 499–527. https://doi.org/10.1007/s11628-023-00529-9.

Zeithaml, Valarie A. 1981. 'How Consumer Evaluation Processes Differ between Goods and Services'. *Marketing of Services* 9 (1): 25–32.

Zhai, Yu, Yan Liu, Minghao Yang, Feiyuan Long, and Johanna Virkki. 2014. 'A Survey Study of the Usefulness and Concerns about Smart Home Applications from the Human Perspective'. *Open Journal of Social Sciences* 02 (January):119–26. https://doi.org/10.4236/jss.2014.211017.