Product Durability: A Systematic Literature Review

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Abstract

Background The shift from durable, rare items to inexpensive, mass-produced goods has resulted in a global phenomenon of economic uncertainty, prompting the necessity for implementing planned obsolescence. However, the intentional creation of products with a limited lifespan resulted in a throwaway culture, which increased the environmental load. This increased load required a shift towards reimagining product longevity and obsolescence to promote responsible manufacturing and consumption.

Methods By employing a two-step systematic review process, this research study investigates the scope of product durability, examining articles from various disciplines published till March 2024.

Results The review reveals the multi-faceted nature of durability, including physical, emotional, and psychological dimensions, and their interconnections with sustainability, technological advancements, and the circular economy. It also delves into product obsolescence and durability, identifying strategies such as resilient, slow, timeless, ageless, and emotionally durable design to combat it. The study aims to offer new insights into creating durable products, addressing unexplored aspects of durability significant in product design and highlighting the challenges designers face in integrating these concepts effectively.

Conclusions The study aims to offer new insights into creating durable products, addressing unexplored aspects of durability significant in product design and highlighting the challenges designers face in integrating these concepts effectively.

Keywords Design Research, Product Durability, Systematic Literature Review

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1. Introduction

The Industrial Revolution reshaped production capacities and consumer preferences, shifting away from valuing scarcity and durable items towards mass production and enhanced availability. However, this shift was not smooth, as the long-lasting products that were initially appreciated and manufactured resulted in unstable economic stability due to lower purchase requirements. This economic instability gave rise to planned obsolescence, where products were made with a shorter lifespan, encouraging repeated consumption (London, 2014). Initially, the implementation of obsolescence focused on addressing physical longevity or the functional longevity of a product. As time has advanced, obsolescence has diversified into various areas, encompassing psychological, economic, and logistical dimensions. While obsolescence has contributed to economic activity, it has also created a transition in consumer behaviour, resulting in a throwaway culture that has increased waste and environmental load over time (Cooper, 2004). The heightened environmental risk prompted the industry to delve deeper into responsible production and consumption by re-thinking the notions of obsolescence and product durability. In the current landscape, the emphasis on creating long-lasting goods, coupled with the changing landscape of product obsolescence, poses a challenge for designers as they navigate the selection and execution of optimal strategies. This underscores the necessity of a thorough grasp of durability, its related principles, and their intricate relationships. A comprehensive examination of contemporary literature concerning product durability, encompassing its diverse facets such as types, methodologies, ramifications, and constraints, is imperative for informing designers and product design processes. Despite some articles delving into durability and product lifespan, they rarely address actionable strategies for designers. The current research endeavours to offer a more inclusive viewpoint on crafting enduring designs by synthesising literature that addresses the longevity of products comprehensively.

This investigation conducts a systematic literature review to delve into and comprehend the principles linked to durability in product design. The aim is to examine existing literature meticulously and unearth fresh insights, shedding light on the application, scope, and constraints within product design. Additionally, the study seeks to pinpoint overlooked facets of durability that bear relevance in the realm of product design.

2. Method

This study employed a two-step approach to carry out the literature review:

i. Initially, data collection entailed conducting a literature search on product durability and strictly adhering to explicit criteria to identify pertinent works.
ii. Subsequent data analysis involved scrutinising the selected research articles on durability within the realm of product design. This was achieved through keyword-based analysis and a critical examination of the concepts associated with durability in the context of product design.

2. 1. Data collection: Systematic search

The literature review began by narrowing down the scope of the knowledge domain, specifically honing in on the concept of durability, with a particular emphasis on tangible artefacts or products. An exploratory systematic search was conducted using two online databases: Google Scholar and Scopus. Scopus maintains stringent quality control and primarily focuses on peer-reviewed articles, allowing us to remove grey literature from Google Scholar's wide range of sources (Moed et al., 2016). The keywords used for the study were "product durability" and "design." The study excluded grey literature due to its low quality. Past literature has adopted a similar approach to ensure source reliability (Mesa et al., 2022). The search and identification of the literature was confined to material science, business and management, social sciences, economics, arts, multidisciplinary, decision sciences, and psychology, as the literature included many articles from various fields like medical, construction, and engineering. Literature published in English about product durability or obsolescence in the context of product design up to March 2024 was considered.

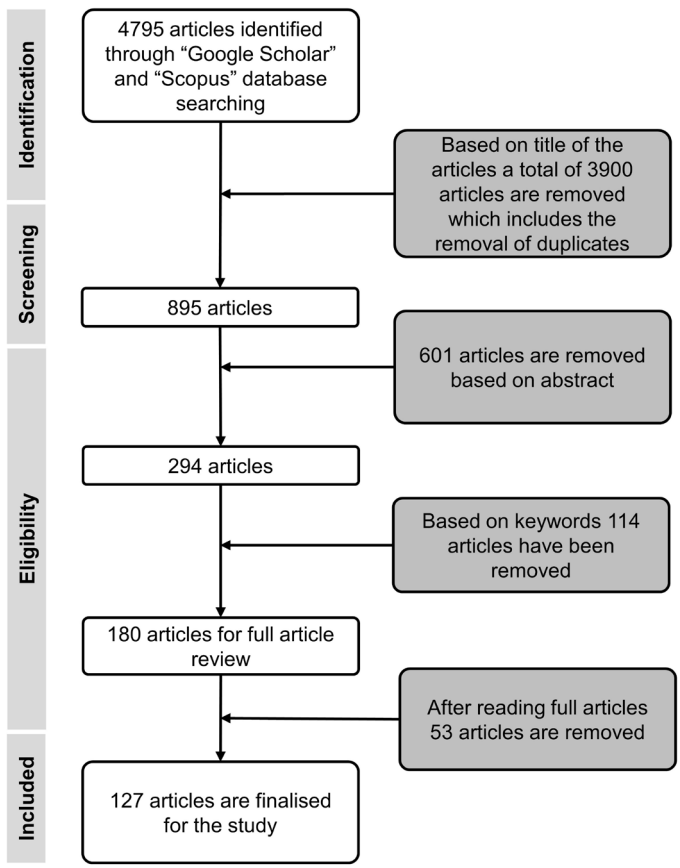

Figure 1 Flowchart of methodology opted in defining literature for systematic reviews

The combined keyword search from both Google Scholar and Scopus databases yielded a total of 4,795 articles. By evaluating the relevance of titles concerning product durability and removing duplicates, the scope of the study was narrowed to 895 articles (see Figure 1). Further scrutiny of abstracts from various perspectives, including studies on physical durability, economic sustainability, and sustainable product development, helped identify

294 articles. Then, keywords associated with product durability, obsolescence, product longevity, or the circular economy helped identify 180 articles. Subsequently, after reading the full articles, 127 articles were selected for literature review. The eligibility criteria for selecting peer-reviewed articles for this study were to consider those that addressed the concepts of product durability, strategies related to product lifespan, or barriers to durability.

2. 2. Data analysis – Keyword–based analysis

This study utilised keyword-based analysis to generate research clusters, providing insight into the distribution within the knowledge domain and assisting in the identification of emerging research directions. This method enabled the monitoring of keyword frequency and their synonyms, specifically focusing on keywords that appeared at least four times for further analysis. The threshold of four was chosen because it optimally balances noise reduction, minimises data loss, and enhances the clarity of the visualisation. In the VOS viewer, a dataset containing the title, abstract, keywords, and year of publication of 127 articles was entered to scrutinise and identify the co-occurrence network, following the methodology outlined by Zhu & Hua (2017) and Mesa et al. (2022). Following this, the identified key terms were analysed to glean insights into the themes encompassing durability, sustainable design, and obsolescence.

3. Results and Discussion

The methodology described facilitated a comprehensive literature review on product durability in product design. The earliest article from the selected list was identified in 1994. Figure 2 depicts that the literature available before the year 2000 on the domain centred around product durability in product design was quite limited.

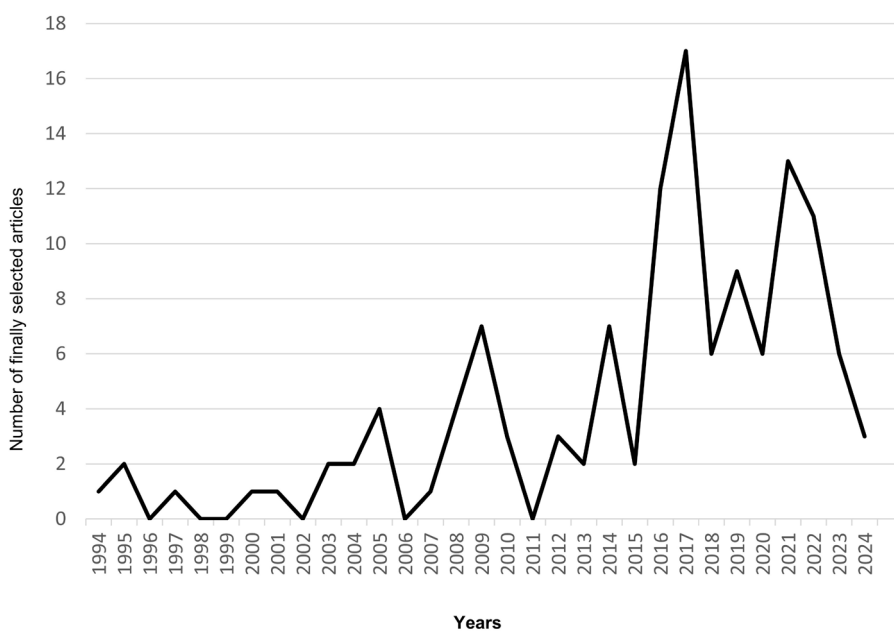

Figure 2 Temporal Distribution of Research Publications by Year and Frequency

3. 1. Keyword-based analysis

Keyword-based analysis was conducted with VOSviewer, which generated keyword networks as illustrated in Figure 3 and Figure 4, facilitating the discovery of key terms (see Table 1), concepts, and trends outlined below. In Table 1, hierarchy of the keywords in each cluster was due to their centrality and connectivity in the keyword network, serving as key integrative nodes. Additionally, they might represent the cluster's defining theme, influencing their prominent placement.

Table 1 Keyword analysis of the identified literature

Keyword	Name of the Cluster	No. of Links	Total link strength	Occurrence
Commerce	Sustainable Product Design and Durability	19	24	5
Design for environment		16	18	4
Durable goods		15	17	4
Durable products		29	58	14
Eco-design		13	15	4
Emotional durability		22	29	6
Extended Producer Responsibility		9	13	4
Manufacture		17	23	4
Optimization		17	23	5
Planned Obsolescence		13	16	5
Product durability		30	42	10
Recycling		23	35	8
User experience		9	10	5
Circular design	Circular Economy and Sustainable Design Strategies	22	43	7
Circular economy		36	97	23
Conceptual framework		17	25	4
Consumer behavior		17	29	5
Consumption behavior		22	31	4
Design method		28	59	9
Design strategies		30	54	8
Emotionally durable design		19	38	8
Longevity		20	28	6
Product development		35	81	16
Product life extension		13	15	4
Product longevity		22	39	11
Life cycle analysis	Sustainable Product Design and Lifecycle Management	16	18	4
Obsolescence		26	50	12
Product attachment		14	19	7
Product design		42	190	43
Product lifetime		18	35	8
Research		17	22	4
Sustainable consumption		16	19	5
Sustainable development		34	99	20

Decision making	Sustainable Decision–Making and Environmental Impact Assessment	12	15	4
Durability		36	93	22
Ecodesign		31	78	15
Environmental impact		20	30	5
Life cycle		26	60	13
Life cycle assessment (lca)		10	18	4
Design	Emotion–Driven Sustainable Design	30	64	15
Emotion		18	24	4
Emotional design		11	19	5
Literature review		13	19	4
Sustainability		38	108	30
Sustainable design		25	48	11

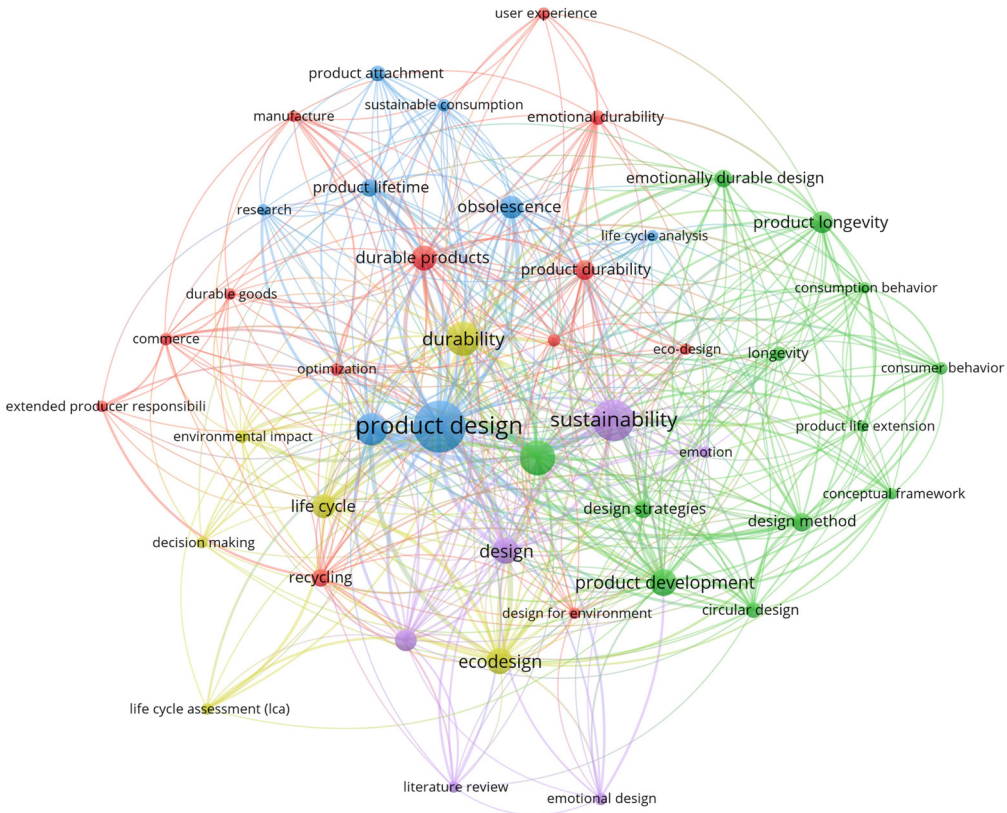

Figure 3 Keyword–based analysis showing network formed through literature

The data acquired from keyword analysis in VOS viewer is from the provided bibliographic data on sustainable design, product durability, and other associated concepts. The keywords, their interlinked concepts, and their relationship within the literature were extracted. The insights are provided below:

a. Central themes and Interconnectedness: The highest occurrence and link strengths were noted for sustainability, product design, circular economy, design, product development, durability and obsolescence, suggesting that the fundamental concepts of durability in product design are associated with sustainable development and

circular economy principles. Moreover, these keywords signify a pattern identified in the literature that involves incorporating sustainability across the entire lifecycle of a product. Product durability and design significantly impact the environment, recycling efforts, and overall ecological footprint. This emphasises the importance of evaluating and minimising the ecological impact through lifecycle assessment.

b. Emerging trends: Emotional durability, emotionally durable design, product lifetime, and product longevity exhibited moderate frequencies but had substantial link strengths. These characteristics define emotionally durable design and related concepts as a growing research area within the context of product design.

c. Gap areas: Extended producer responsibility and user experience display fewer links and instances, suggesting opportunities for future research into incentivising producers for product longevity and integrating user experience into sustainable design practices.

d. Design consideration: Occurrences of product lifetime, user design method, and life cycle assessment (LCA) are limited, indicating a deficiency in practical application and methodologies for prolonging product lifetimes through design. This suggests more research into integrating various product life-extending strategies into the design process.

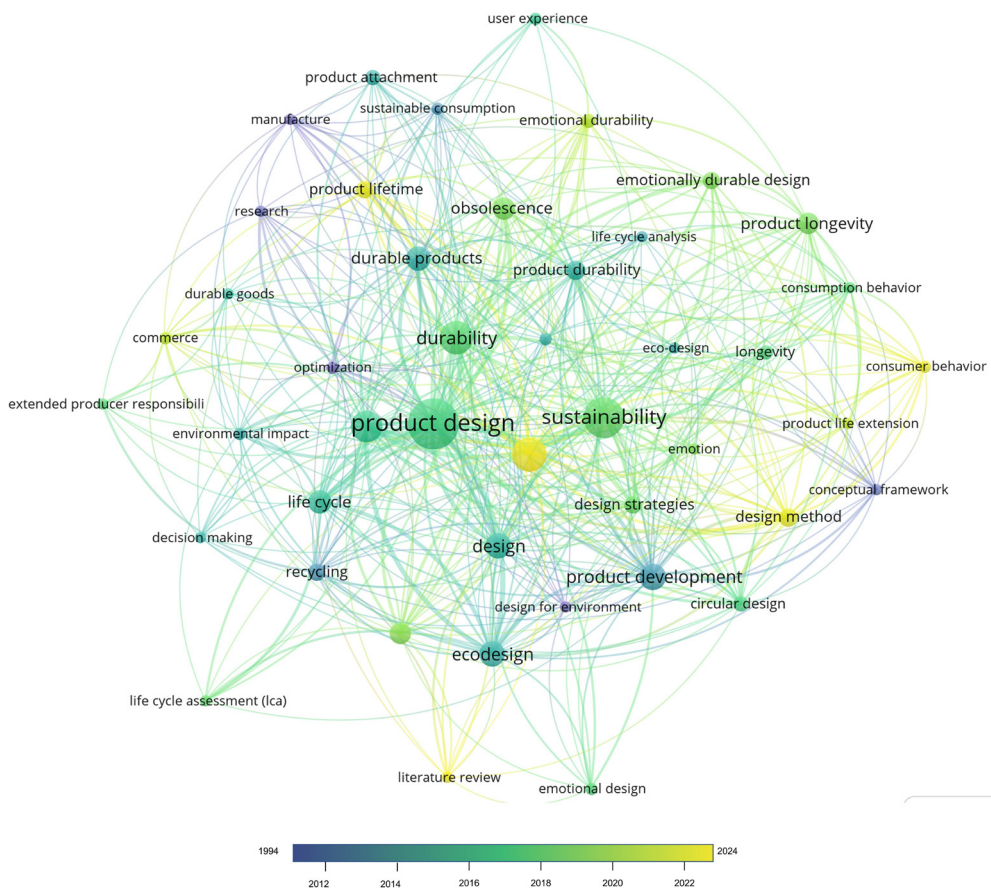

Figure 4 Keywords from research mapped across years

The map shown in Figure 3 illustrates five distinct clusters, each differentiated by a unique colour. Figure 4 shows how the data's trends changed overtime by presenting the average publication year of documents associated with each keyword.

Exploring product durability in sustainable product design is important to address obsolescence and environmental impact. The following sections depict dimensions and implications for design.

3. 2. Product Durability

Product durability refers to the ability of a product to maintain its functionality and performance over time (J. Chapman, 2009; Haug, 2018; Mesa et al., 2022). Various domains such as electronics, automotive, fashion, and household appliances have explored product durability in literature (J. A. Chapman, 2008; Kam, 2021; Mulet et al., 2022; Proske et al., 2016). Initially, durability was characterised solely in terms of a product's physical dimension; however, it has since evolved to encompass the product's capacity to withstand changing consumer preferences and technological advancements. Product durability includes various dimensions that include physical robustness, emotional significance, and adaptability to technological advancements (Haines-Gadd et al., 2018; Haug, 2019; Mesa et al., 2022). Understanding and effectively managing product durability is critical to implementing circular economy and sustainable development, as durable products reduce waste, minimise resources, and limit environmental pollution by reducing product replacement through increased product lifespan (Den Hollander et al., 2017; Joustra et al., 2021). Products that last longer provide more value to consumers as they reduce the need for replacements and provide enough time for users to connect emotionally with the product (J. Chapman, 2009).

3. 2. 1. Dimensions of Product Durability

Throughout the literature, product durability has been broadly categorised into four aspects, which are as follows:

i. *Physical durability*: Physical durability refers to the lifespan of products and their functional ability; this can define how long a product can preserve itself from degrading under environmentally aggressive forces and perform its intended functions (Den Hollander et al., 2017; Joustra et al., 2021). The robust design is adapted to achieve the highest possible functional life for products and parts. Xing & Belusko (2008) envision physical durability as a circular design strategy for product longevity, encompassing repairability, maintainability, and upgradeability.

ii. *Emotional Durability*: Emotional durability has gained significance in product design, particularly in addressing the disposable nature ingrained in our consumer culture. Emotional durability defies obsolescence by increasing a product's lifespan through embedding and enhancing the user's emotional significance with the product (J. Chapman, 2009; Haines-Gadd et al., 2018; Huang et al., 2023). Emotionally driven longevity complements a product's physical durability by creating an emotional resonance that helps foster sustained user engagement (Haines-Gadd et al., 2018; Mesa et al., 2022). Emotional durability was explored through a six-point experiential framework, which included narrative, detachment, attachment, surface, fiction, and consciousness (J. Chapman, 2009). This method

addresses symbolic obsolescence, emphasising emotional attachment over functional/economic factors, which leads to product lifespan extension (Cooper, 2004).

The effectiveness of emotional durability in achieving product longevity becomes critical, especially for products susceptible to rapid consumption cycles (Goworek et al., 2020). Incorporating emotional durability into the design process also fosters the development of circular economic business models, such as second-hand markets and product-service systems, emphasising prolonged use rather than product ownership (Claxton & Kent, 2020). The literature underlines personal memories, the enjoyment of use, and self-expression are fundamental elements that contribute to establishing lasting emotional connections (Maclachlan et al., 2009; Page, 2014; Schifferstein & Zwartkruis-Pelgrim, 2008). Furthermore, literature provides examples highlighting emotional durability and attachment principles in creating products that foster profound emotional connections, enabling products to endure the test of time physically and emotionally (Grosse-Hering et al., 2013; Gulden et al., 2010; Huang et al., 2023; Ji & Lin, 2022; Kam, 2021; Ko, 2017; Lacey, 2009; Mulet et al., 2022; Padró, 2014; Rodrigues, 2010; Van Krieken et al., 2012).

iii. *Psychological Durability*: Psychological durability is defined as a product's ability to meet the user's psychological needs over time, creating an attachment and dependency, making the product irreplaceable (Haug, 2019). This considers emotional and aesthetic appeal and focuses on functionality to provide psychological relevance. Haug (2018) delved into psychologically durable design, a concept encompassing broader dimensions than the emotionally durable design delineated by Chapman (2009). Psychological and emotional durability are devised to counteract psychological obsolescence, evolving to delineate various forms of durability and obsolescence.

iv. *Strategic Durability*: Strategic durability emerges as a holistic concept that intertwines a product's tangible longevity with a company's overarching strategic goals, emphasising sustainability, market presence, and stakeholder value generation. This multi-faceted approach to product development is characterised by creating offerings that align with enduring consumer needs, competitive differentiation, and corporate environmental objectives (Haase, 2023; Haase & Laursen, 2022). It aims to bolster brand allegiance, ecological responsibility, and financial viability by marrying the durability of products with a company's core mission and ethical standards. Integral to this strategy is digital product passports (DPPs), which serve as instruments for transparency, fostering consumer engagement, and ensuring that products reinforce the principles of a circular economy and sustainable commerce, as Plociennik et al. (2022) noted. Strategic durability, therefore, encapsulates a comprehensive view of product life span that integrates the physical, emotional, and psychological aspects of durability with the strategic necessities of contemporary business dynamics.

3. 2. 2. A case study to help demonstrate the differentiation of durability concepts:

Many times, few concepts of durability overlap; however, they always have different focuses and aims when achieving durability in a product. A simple smartphone example can help demonstrate how these are different.

- Physical durability: A smartphone with a water-resistant case and Gorilla Glass demonstrates robustness and resistance to drops and elements. These keep the phone functional and physically intact.
- Strategic durability: A smartphone company designs its products with recyclable materials and promotes buyback. It aligns with the company's environmental goals. This strategy appeals to environmentally conscious consumers and enhances brand reputation. Increased consumer trust and loyalty can increase sales, supporting economic sustainability.
- Emotional durability: A smartphone with advanced technology and 2000s iconic aesthetics evokes nostalgia, enhancing emotional attachment through memories. Smartphones with customisable features can form an emotional bond with users, making them less likely to discard them.
- Psychological durability: A smartphone with stress and sleep monitoring helps manage health and meet psychological needs. Smartphones' adaptive user interfaces, which learn users' habits, reduce digital stress and boost productivity. With time, people find it challenging to switch brands or goods due to the interface's efficiency and convenience.

Overlap between emotional and psychological durability

Among these types of durability, two types often coincide: emotional and psychological durability, which aim to strengthen the user's relationship with the product and make it an integral part of the user's life. The interaction between emotional and psychological durability is a mutually influential relationship where each factor influences the other, enhancing user attachment and satisfaction. Emotional durability in smartphones is achieved in many ways. One such method is aesthetic customisation, which allows users to personalise their devices. This fosters an emotional bond through positive feelings and a sense of ownership. The smartphone reinforces the emotional bond by fulfilling psychological needs, streamlining the user interface and reducing cognitive load, enhancing the user's psychological state. Hence, characteristics that enhance psychological comfort can also boost emotional connection and vice versa, illustrating a dynamic collaboration that ensures the product is appealing and practical, thereby optimising user engagement and device durability. Another instance of this phenomenon is when a smartphone's artificial intelligence (AI) assistant customises interactions by imitating empathy and organising tasks to lessen mental effort and enhance daily productivity, rendering it an essential and emotionally comforting tool.

3. 3. Product Obsolescence:

Product obsolescence is the process by which a product becomes outdated or no longer helpful. A precise understanding of product obsolescence is essential to ensure a product's longevity (Yamamoto & Murakami, 2021). An extensive exploration has been conducted on product obsolescence, examining numerous pathways through which a product may become obsolete (Agrawal & Ülkü, 2013; Koenigsberg et al., 2011; Maitre-Ekern & Dalhammar, 2016;

Maulia & Halimatussadiah, 2018; Pardo-Vicente et al., 2022; Poppe et al., 2021; Schallmo et al., 2012; Sierra-Fontalvo et al., 2023; Valusyte, 2021; Yamamoto & Murakami, 2021).

Details of the same are summarised below (Cooper, 2004; Schallmo et al., 2012; Sierra-Fontalvo et al., 2023; Yamamoto & Murakami, 2021):

a. *Technological obsolescence*: This obsolescence replaces older product versions with newer ones, promoting technological progress. Technological obsolescence makes the older versions depreciable, even if they are functional. This obsolescence is a combination of technical and compatibility-caused obsolescence. Technological obsolescence replaces the old one by making the user perceive the product as outdated. This is closely related to the psychological aspect (Haug, 2019; Sierra-Fontalvo et al., 2023).
b. *Functional obsolescence*: Products become obsolete when they no longer meet performance requirements, cannot be upgraded, or lack necessary features and functionalities for the current usage context (Sierra-Fontalvo et al., 2023).
c. *Psychological obsolescence*: The desirability of a product diminishes due to changing consumer preferences or design trends, regardless of its lifespan. This is caused by psychological, aesthetic, and stylistic obsolescence. The literature cites this obsolescence in addressing psychological and emotional durability (Sierra-Fontalvo et al., 2023).
d. *Economic obsolescence*: This obsolescence is observed when maintaining or using an existing product becomes less economically viable than replacing it with a new one (Sierra-Fontalvo et al., 2023).
e. *Diminishing manufacturing sources and material shortages (DMSMS)*: This obsolescence occurs when essential components, materials, or technologies become unavailable due to discontinuation or supply chain disruptions, affecting the product's maintainability and upgradeability (Sierra-Fontalvo et al., 2023).
f. *Planned obsolescence*: This happens due to the production of parts with lowered life compared to what is technically possible. This obsolescence makes the products fail, compels product replacement, and increases repeat sales (Sierra-Fontalvo et al., 2023).
g. *Optional obsolescence*: This obsolescence arises when product manufacturers continue producing products with outdated technology, leading to a natural decrease in demand as consumers choose more modern alternatives (Mellal, 2020).
h. *Ecological obsolescence*: Products replaced due to their adverse impact on the environment beyond acceptable limits are termed ecological obsolescence (Schallmo et al., 2012).
i. *Social obsolescence*: This form of obsolescence arises from a shift in societal perception of a product prompted by changes in social norms or values (Schallmo et al., 2012).
j. *Legal obsolescence*: This obsolescence arises when products can no longer be used because they are deemed illegal or non-compliant with legislative requirements (Schallmo et al., 2012).

3. 3. 1. Categorising Obsolescence

Broadly, the ten obsolescence can be classified into four categories, which are as follows (shown in Figure 5):

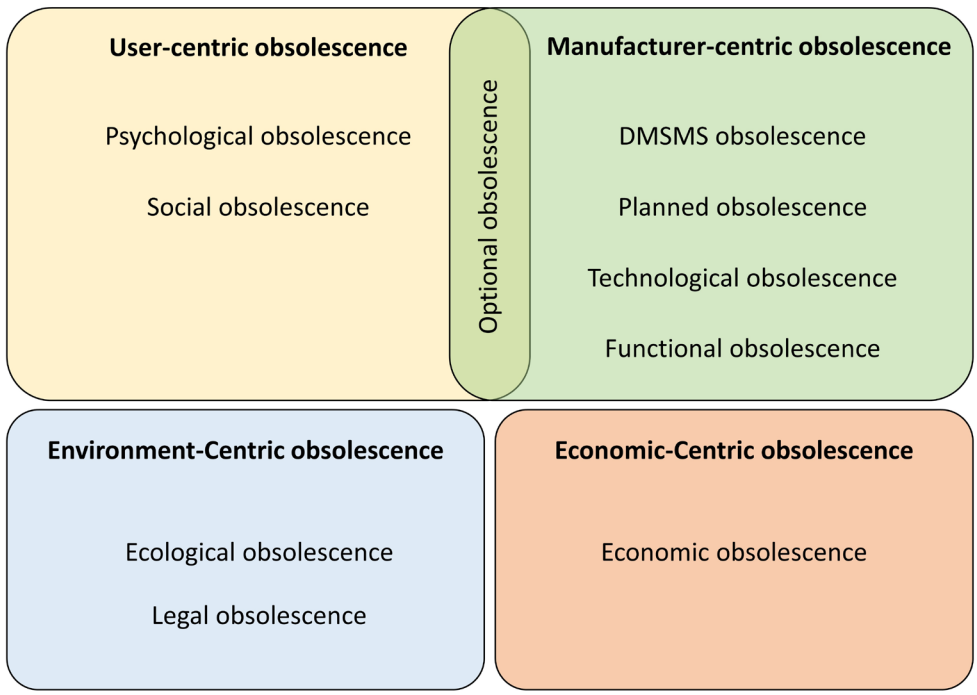

Figure 5 Obsolescence categories

a) *User-centric obsolescence*: This category is defined by its emphasis on the impact of shifts in consumer's perceptions and behaviours, including psychological and social obsolescence that impact and result in these changes.

b) *Manufacture obsolescence*: This category explicitly addresses aspects of product production, design, and material composition. Manufacture obsolescence includes diminishing manufacturing sources and material shortages (DMSMS), and planned, technological, and functional obsolescence is categorised as manufacturing obsolescence.

c) *Environment-centric obsolescence*: This category includes obsolescence that is driven by environmental and regulatory factors. Ecological and legal obsolescence are categorised as environment-centric obsolescence.

d) *Economy-centric obsolescence*: This category encompasses financial variables that affect the product's viability and consumer interest to purchase or maintain it. Economic obsolescence is included in this classification.

e) Optional obsolescence, which considers consumers' preferences and manufacturing choices, is classified into user-centric and manufacturing-centric categories.

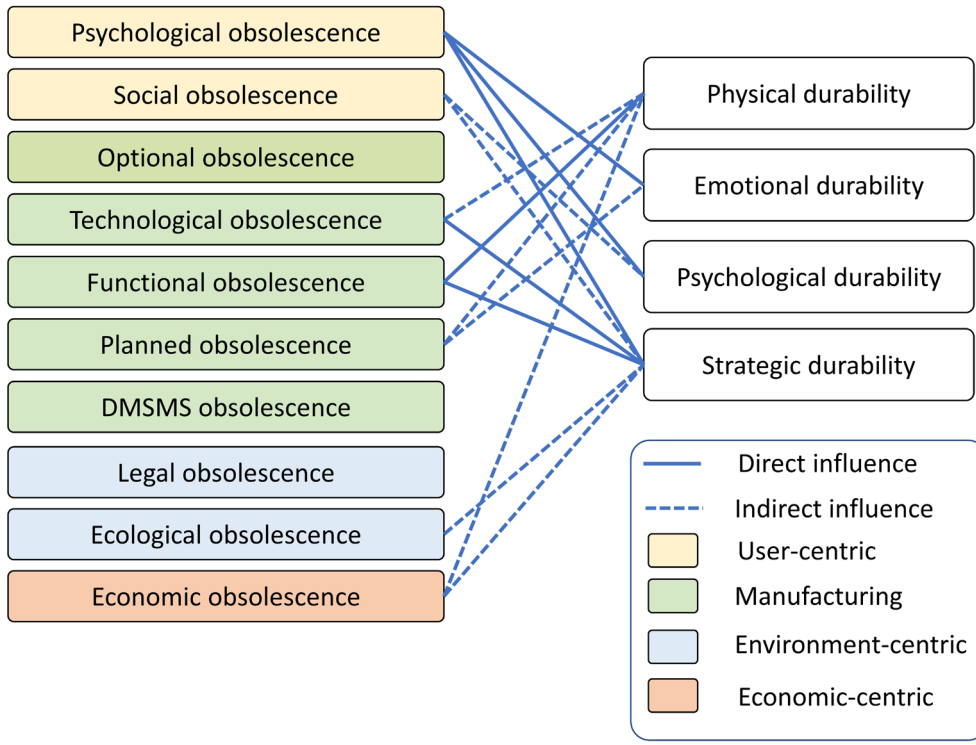

Figure 6 The interplay of durability and obsolescence

Understanding the relationship between obsolescence and durability in contemporary contexts is crucial to recognise that durability strategies are primarily framed from the user's viewpoint, suggesting room for investigating durability concepts from the manufacturer's standpoint (Figure 6).

a. Physical durability of a product guarantees its functional life and contributes to its robustness and longevity, directly impacting functional obsolescence (Becher & Sibony, 2021). Furthermore, physical durability indirectly affects economic obsolescence by reducing the expenses associated with product replacement and maintenance (Sierra-Fontalvo et al., 2023).

b. Emotional durability directly confronts psychological obsolescence by strengthening the emotional connections between products and their users (Sierra-Fontalvo et al., 2023). Additionally, this indirectly alleviates the issue of planned obsolescence, as enduring user loyalty aids in prolonging the product's operational lifespan and reducing the frequency of replacements.

c. By satisfying the psychological needs of users and fostering a lasting attachment to products, psychological durability directly combats psychological obsolescence (Haug, 2019; Sierra-Fontalvo et al., 2023). Additionally, it indirectly influences planned obsolescence by nurturing enduring emotional connections and diminishing the perceived necessity for frequent product replacements.

d. Strategic durability ensures that products remain competitive, sustainable, and adaptable to changing demands and preferences in various dimensions of durability with strategic business goals. This durability defies functional, technological,

and psychological obsolescence by creating adaptable, relevant, and appealing products. Abiding by long-lasting consumer and societal values indirectly influences economic, ecological, and social obsolescence (Haase, 2023).

The literature on circular design indicates that two approaches to addressing obsolescence exist: resistance and postponement. Resistance to obsolescence involves reinforcing physical and emotional durability while postponing obsolescence, which entails designing products capable of maintenance, upgrading, recontextualisation, repair, refurbishment, and remanufacturing.

3. 4. Strategies to achieve product longevity and sustainable product development

Approaches found within the durability literature linked to enhancing product longevity include:

a) *Resilient design*: The design philosophy and approach prioritise creating products capable of adapting to environmental, usage, emotional, and psychological changes. This approach underscores the importance of designing for flexibility, adaptability, robustness, and ease of repair and maintenance. Such a strategy ensures that the product remains functional and valuable to users (Haug, 2018).

b) *Slow design*: This strategy is regarded as a sector characterised by a deliberate pace. It aims to produce products that decelerate consumption and have extended lifespans. This is primarily achieved by crafting visually captivating and emotionally compelling products (Grosse-Hering et al., 2013).

c) *Timeless design*: Timeless design entails crafting products that transcend trends and endure over time by blending aesthetic appeal with functionality (Lobos, 2014). Achieving timeless design involves considerations such as appearance, product efficiency, material selection, and user experience (Lobos, 2014). Flood Heaton and McDonagh (2017) emphasise timelessness through exceptional beauty, nostalgia, and simplicity. This design approach is often linked to classicism, anti-fashion, simplicity, and minimalism (Lobos, 2014; Zafarmand et al., 2003).

d) *Emotionally durable design*: In pursuit of entirely sustainable products, Chapman (2009) has advocated for emotionally durable design, encompassing dimensions such as attachment, fiction, consciousness, narrative, detachment, and surface. Haines-Gadd (2018) delved further into the concept of emotional durability, aiming to comprehensively address psychological and emotional obsolescence within the context of product longevity. This new approach to emotionally durable design introduces nine themes to achieve emotional durability: narrative, integrity, identity, relationship, imagination, materiality, evolvability, consciousness, and conversation.

e) *Psychologically durable design*: Haug (2019) introduced this concept, which outlines how specific products achieve durability by upholding their values. The study reported by Haug (2019) elucidates the distinctions between emotionally and psychologically durable designs, illustrating how certain products can achieve durability due to specific attributes in particular contexts. Psychologically durable design is characterised by qualities such as timelessness, exclusivity, personality, personalisation, and ageing gracefully. Psychologically durable design aims to psychologically uphold the product's value by preserving its instrumental, hedonic,

and symbolic significance (Haug, 2019). This novel concept of durability expands the scope by suggesting that the product's design elements can enhance appeal over time.

f) *Circular design*: This strategy involves creating products by integrating principles of the circular economy into the design process to develop sustainable and environmentally friendly products. The strategy aims to reduce waste by encouraging product reuse, refurbishment, and recycling to extend product integrity and material integrity (Bocken et al., 2016; Joustra et al., 2021). The inertia principle introduced by Walter Stahel suggests not repairing a product when something is not broken, not remanufacturing when something can be repaired, and not recycling if something can be remanufactured (Den Hollander et al., 2017; Walter, 2016). Adhering to this order of applying principles informs which strategies to use.

Figure 7 depicts the interconnections between various sustainable design philosophies. Psychologically durable design is centred around emotionally durable design, which emphasises the development of strong emotional connections between users and products. This approach extends these connections to align with the evolving psychological values of users. Resilient design encompasses the idea of being adaptable to both environmental and usage changes. Resilient design is a subset of slow design that aims to reduce consumption by extending product lifespans. Timeless design distinguishes slow design, ensuring both aesthetic and functional durability. The circular design incorporates the principles of reuse and recycling, including slow design but excluding emotionally charged designs, focusing on material sustainability.

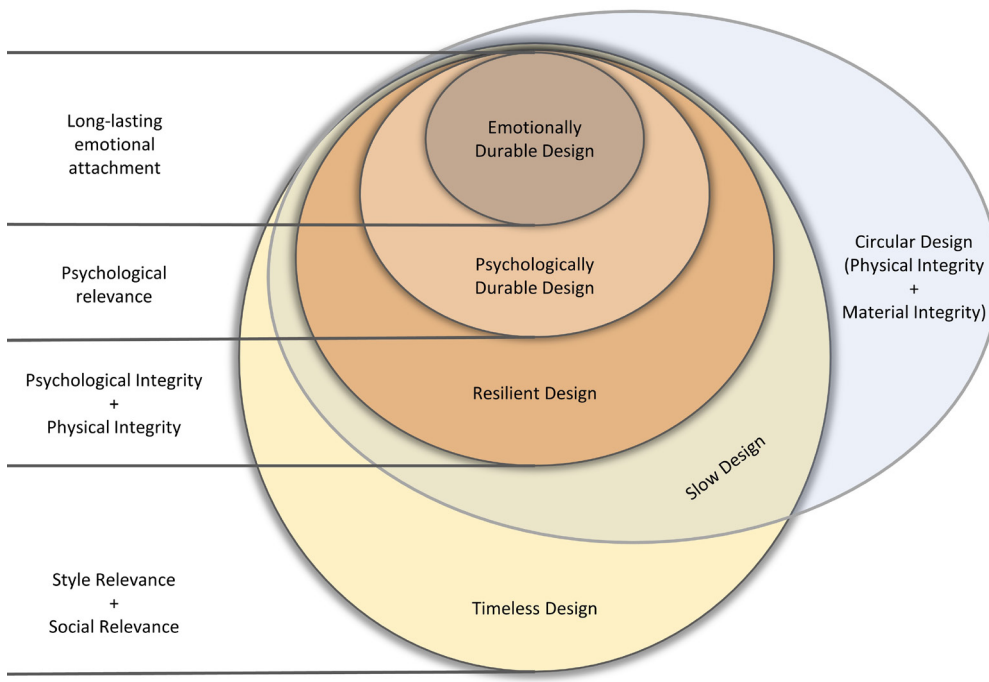

Figure 7 Design strategies that influence product lifespans'

Additionally, Table 2 illustrates how the identified strategies align with different product lifespans related to durability. This alignment describes strategy for designing products with specific lifespans. It emphasises obsolescence, which refers to product integrity that extends beyond a single lifespan via recovery strategies for functionality across multiple cycles. Product integrity combines durability and recovery to improve longevity via long life (inherent longevity, extended use, and reuse) and lifetime extension (repair, maintenance, and upgrading). Table 2 illustrates these strategies for increasing product longevity.

Table 2 Keyword analysis of the identified literature

Code	Strategy	Timeless design	Slow design	Resilience design	Emotionally durable design	Psychologically durable design
Long life	Long inherent life			X		
	Long use	X	X	X	X	X
	Reuse			X	X	X
Life extension	Repair and maintenance		X	X	X	
	Upgrade		X	X	X	X

Achieving Long-Life:

a. Long inherent life: This concept centres on naturally enduring designs. Resilient design emphasises flexibility and robustness, ensuring products withstand changes and stresses, extending their useful life.
b. Long use: This involves designing products to remain useful for an extended period before needing replacement. Strategies such as timeless, slow, emotionally durable, and psychologically durable designs support this by ensuring products stay relevant and desirable over time.
c. Reuse: This pertains to a product's ability to extend its use beyond its initial lifecycle. Resilient, emotionally durable, and psychologically durable designs promote repeated use, making the products suitable for multiple use cycles.

Achieving life extension:

a. Repair and maintenance: This involves strategies to ensure products can be easily repaired or maintained, thus extending their lifespan. Resilient, slow, and emotionally durable design strategies support this by emphasising ease of repair and robustness.
b. Upgrade: This category focuses on adapting existing products to changing needs or technologies rather than replacing them. Strategies such as resilient, slow, emotionally durable, and psychologically durable designs support this approach by emphasising flexibility and enduring appeal.

3. 4. 1. Mapping obsolescence and various sustainable product development strategies

Sustainable design strategies are mapped with obsolescence to inform the ability of the strategy to mitigate different types of obsolescence, as shown in Figure 8.

a) *Timeless design*: This strategy emphasises classic aesthetics, functionality, and high-quality material to create products that stay relevant even with changing

trends and consumer preferences (Lobos, 2014). Timeless design directly influences and defies psychological obsolescence by keeping the product's aesthetic relevant to the user (Haug, 2019). Timeless design indirectly combats social obsolescence as classic designs remain socially acceptable over longer periods. This also indirectly impacts ecological sustainability by reducing the necessity for frequent product replacements.

b) *Slow design*: This represents a holistic approach that contrasts with rapid consumption patterns. This design philosophy seeks to establish strong bonds between the user and the product, extending its lifespan and reducing the need for frequent replacements. Thus, this directly counters psychological obsolescence (Haines-Gadd, 2019). Slow design directly influences functional and technological obsolescence by promoting easy product maintenance and upgradeability (Park, 2005). Furthermore, slow design indirectly influences ecological and economic obsolescence by nurturing sustainable consumption and long-lasting products. This philosophy also indirectly confronts social obsolescence by cultivating a culture that values longevity and meaningful consumption.

c) *Circular design*: This approach aims to reduce waste by considering the entire lifespan of a product by emphasising reuse, recycling, and upcycling (Suppipat & Hu, 2022). Therefore, this philosophy directly confronts technological obsolescence by allowing products to evolve or adapt to changing technological advancements. Moreover, the implementation of circular design encourages prolonging the useful lifespan of a product, thereby tackling the issue of economic obsolescence. This also plays a role in reducing purchase frequency, which is essential for mitigating ecological obsolescence. Furthermore, circular design indirectly promotes social sustainability by encouraging the cultivation and evolution of societal values towards sustainability.

d) *Emotionally durable design*: This strategy aims to create products that establish a profound emotional bond with users, thus extending the product's lifespan. Emotionally durable design strategies directly tackle psychological obsolescence by fostering an emotional connection (Haines-Gadd, 2019). Promoting such emotional connection also encourages users to maintain and care for their products, thereby confronting functional obsolescence. Moreover, emotionally durable design indirectly counteracts social obsolescence by creating products that surpass societal trends in their cherished value.

e) *Psychologically durable design*: This strategy focuses on meeting the user's psychological needs in order to prolong the product's relevance and value, effectively countering psychological obsolescence (Haug, 2019). Ensuring that products sufficiently fulfil needs over an extended period reduces the desire for replacement and indirectly promotes economic sustainability by prolonging the product's lifespan. Additionally, this design approach can indirectly address the problem of functional and social obsolescence by ensuring that the product continues to meet user demands and remains pertinent to evolving social standards. This approach highlights the importance of achieving psychological satisfaction to improve a product's durability and sustainability.

f) *Resilient design*: This strategy focuses on creating products that can adapt and recover from various challenges, such as damage, wear, and technological advancements (Haug, 2018). It integrates adaptability, repairability, and upgradeability to address functional and technological obsolescence. Resilient design mitigates DMSMS obsolescence by ensuring products can function with alternative components or materials (Zolghadri et al., 2021). This reduces reliance on scarce resources and addresses immediate obsolescence issues. It also promotes social durability by keeping products relevant amid changing societal norms and technological advancements. Additionally, resilient design tackles psychological and ecological obsolescence by enhancing product durability and flexibility, thereby increasing user satisfaction and reducing waste.

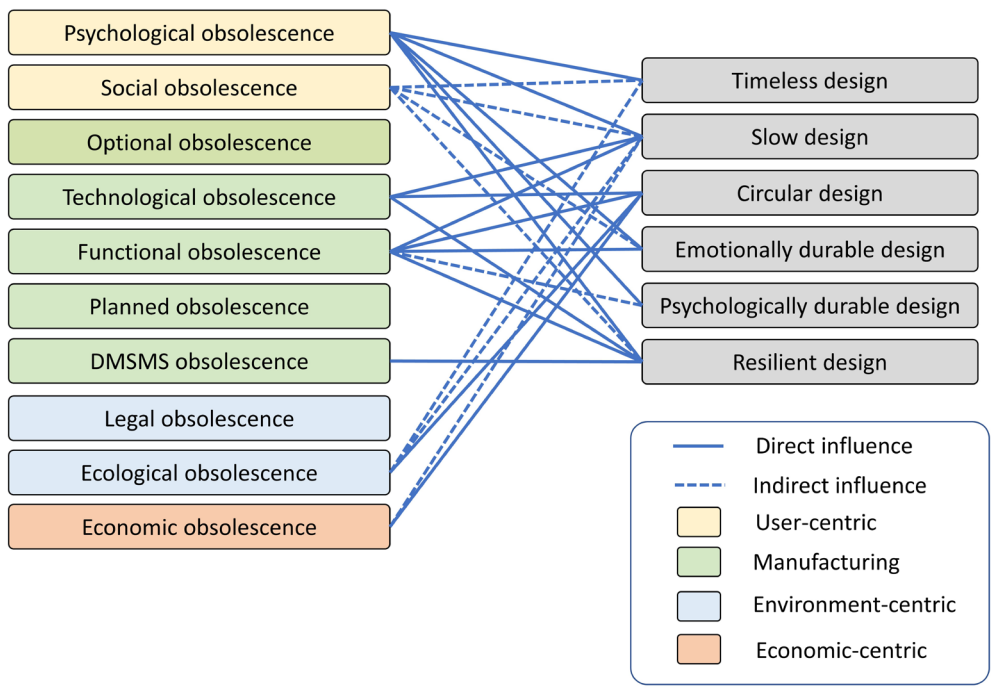

Figure 8 The interplay of sustainable design strategies and obsolescence

Figure 6 depicts the various types of obsolescence and their direct and indirect relationship to the different product durability concepts, such as physical, emotional, psychological and strategic. Figure 7, on the other hand, shifts focus towards sustainability design strategies that are closely associated with product durability. It illustrates how timeless, slow, circular, emotionally durable, psychologically durable and resilient designs interact with various obsolescence types.

Further, upon analysis, Figures 6 and 8 reveal that durability strategies are primarily defined from the user's perspective. This observation suggests an opportunity to explore durability concepts from the perspectives of manufacturers, environmental and economic considerations, particularly regarding the choices made by designers.

4. Identifying unstudied phenomenon in durability

The literature on emotionally and psychologically durable design explains a process that aims to prolong a product's utility, maintain the relevance of its features and forms, and foster user attachment. For instance, the Mini Cooper incorporates several design features that endure over time, attributed to its timeless brand DNA (Laursen & Barros, 2022). However, some design decisions, such as the design of car interior space, are not only influenced by emotional or psychological durability but also by regulatory requirements. This indicates that regulations on manufacturers influence the design choices while designing a product. Current literature on product durability largely overlooks these decisions made by designers. Additionally, existing literature on durability does not explore why specific features persist across time within a product category and endure longer. For example, the prevalence of flip-top caps on shampoo bottles raises questions about whether this feature persists due to cost considerations or the familiarity and simplicity of its functionality. This lack of clarity regarding continuity suggests that while existing concepts may explain why certain functions or features endure, they do not fully define the uncertain continuity of features. We define this ability of the features to continue existing across products, their iterations, and multiple product lives as design-durability. This new aspect is not entirely addressed by durability and other sustainable design strategies, which are predominantly framed from the user's perspective. Therefore, it is a new area of inquiry that requires exploration from the designers' perspective rather than solely from the users. Figure 10 informs how the perspective of designers differs from that of users.

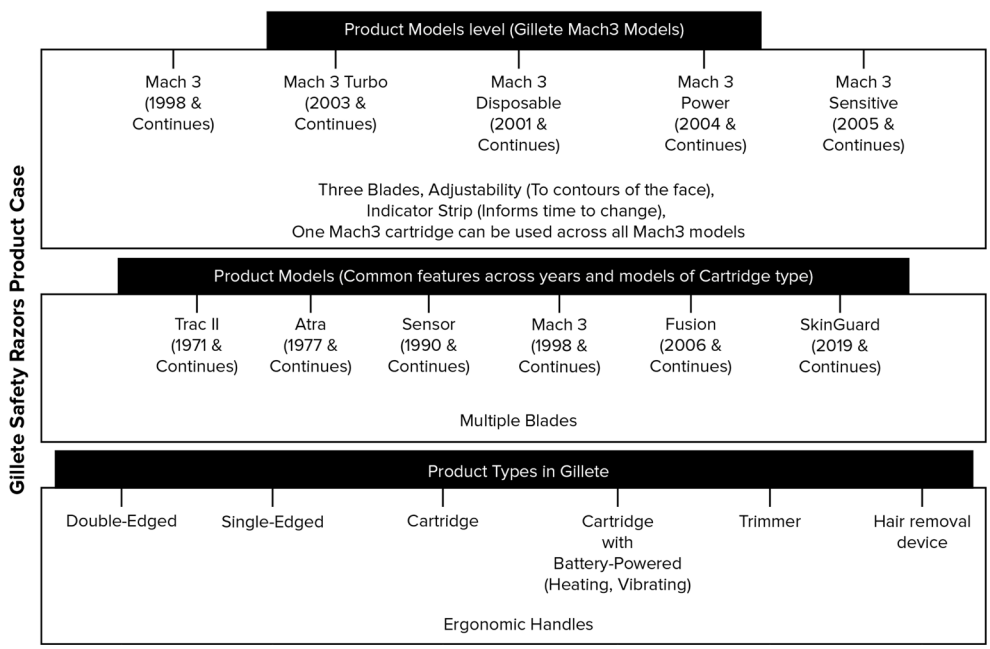

Figure 9 Product and design durability of a product

Product durability and design-durability are fundamentally different, as the former defines the long life of a single product, and design-durability defines the market endurance of a design or feature. An example of how design-durability varies across various product types and models of Gillette-manufactured products is shown in Figure 9. Though Gillette's five-blade model was introduced as a feature to increase the multi-directional adjustability of the blades according to facial contour, the three-blade model continued to be used and is available in the market. This implies that the three-blade model is still acceptable in many ways. This suggests that design-durability is not limited to the overall product concept but also to its features that appear to be durable across product models (Gillete Mach3 model safety razor) and product types (Cartridge type safety razor).

Few other examples that depict the concept of design-durability are as follows:

a) *Smartphone Charging Ports*: The shift from micro-USB to USB-C across various digital products demonstrates design-durability through technical advancements and widespread adoption, enhancing interoperability and user experience.
b) *Automotive Dashboards*: Speedometer placement across various dashboard layouts, despite evolving digital technology, highlights design-durability in maintaining usability across vehicle generations.
c) *Keyboard Layout*: The continued use of QWERTY layout across devices from typewriters to digital screens showcases design-durability by facilitating ease of learning and transition.
d) *E-book Readers*: The use of traditional book-like forms in e-book readers showcases design-durability through its focus on readability and comfort.
e) *Bicycle Frame Geometry*: The consistent geometry of bicycle frames, regardless of new materials or techniques, demonstrates design-durability in terms of performance and comfort.
f) *Watch Crown Mechanism*: The continued use of the crown mechanism for tactile interaction in watches, despite the digital era, highlights design-durability for utility and aesthetic connection.
g) *Flight Control Stick*: Enduring design and functionality of flight control sticks in aircraft, preserving intuitive control, demonstrates design durability.
h) *Screw Threads and Fasteners*: Standard designs facilitating compatibility and repairability across applications underscore design-durability in assembly.
i) *Pencil Design*: The enduring design of the wood-cased graphite pencil, despite new writing technologies, reflects design durability in form, function, and usage.
j) *Manhole Covers*: The simple, effective round design that prevents accidental fall-through in urban infrastructure exemplifies functional design-durability.

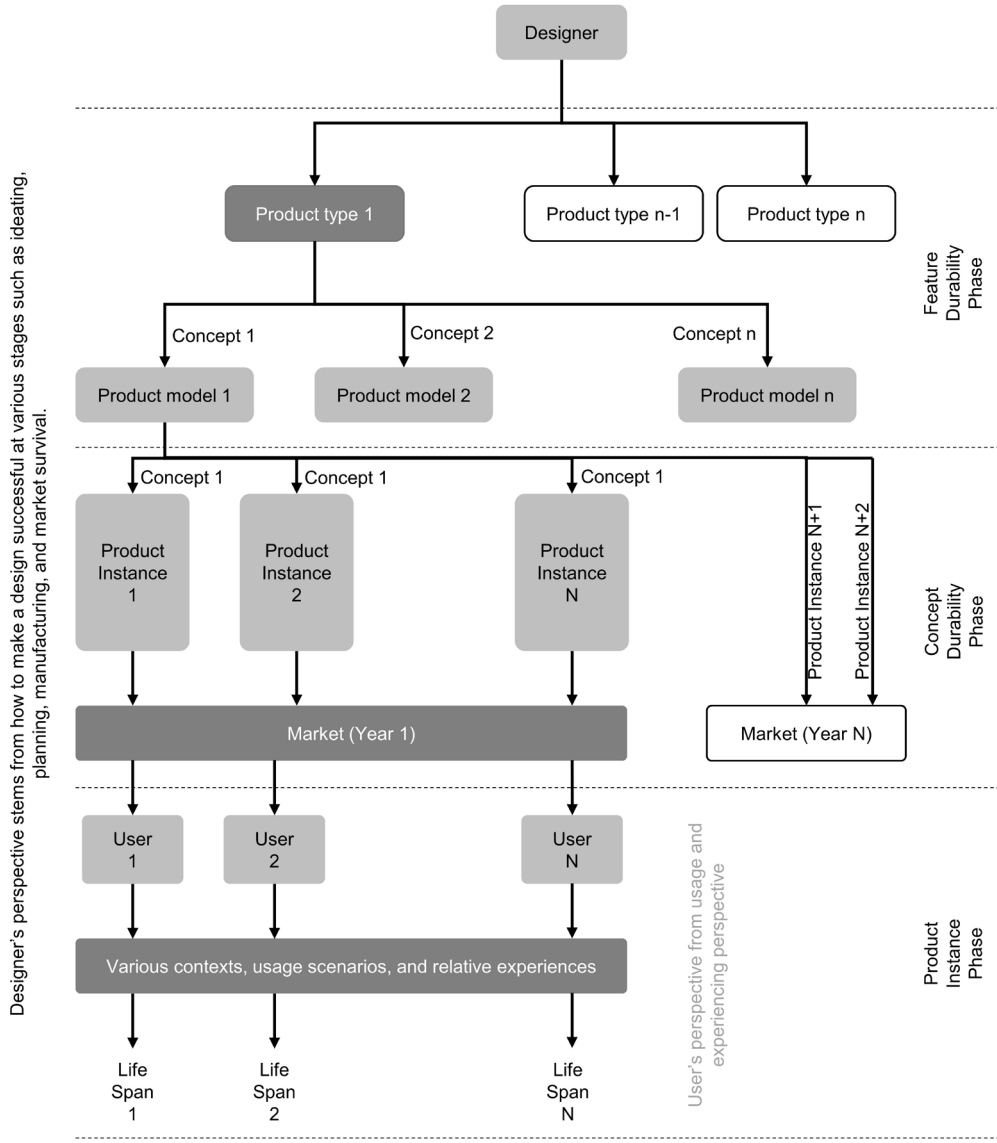

Figure 10 Designer and user perspective on durability

4. 1. Design–durability conceptual placement

Designs crafted with principles of design durability inherently prioritise sustainability from a multi-faceted standpoint. The distinction in philosophy is outlined in Table 3 and Table 4 below.

Table 3 Comparative overview of design–durability and related concepts in the literature

Design–Durability overlapping concepts	Definition	Difference of the concept with Design–Durability
Physical Durability	The product's ability to resist environmental and physical stresses to continue performing its intended functions over time (Den Hollander et al., 2017; Joustra et al., 2021).	Physical durability makes a product resist environmental and physical stresses over time, while design–durability focuses on the persistence of design features.
Emotional Durability	This durability provides the ability for the product to form and cultivate a strong emotional attachment to a product, helping it deter product replacement (J. Chapman, 2009; Haines–Gadd et al., 2018; Huang et al., 2023).	Unlike design–durability, which focuses on consistent design features across products, emotional durability targets the relationship between a single product and its user.
Psychological Durability	The psychological durability of a product is to meet the user's psychological needs over time (Haug, 2019).	Psychologically durable design helps maintain long–term user appeal, and it is also critically detailed to address the lifespan of the product instance usage. While design–durability ensures consistent design and functionality across products, focusing on lasting presence rather than user attachment.
Strategic Durability	This concept helps intertwine a product's longevity with a company's strategic goals, emphasising sustainability, market presence, and value generation for stakeholders (Haase, 2023; Haase & Laursen, 2022).	Strategic durability aligns a product's lifespan with a company's sustainability and market goals. Design–durability focuses on the adaptability and longevity of design features, enhancing user experience without encompassing broader corporate strategies.
Timeless Design	Timeless design helps create products that transcend trends (André & Nilsson, 2024; Christiansen et al., 2010; Flood Heaton & McDonagh, 2017; Lobos, 2014; Shin et al., 2021; Shin & Ghim, 2020; Spreafico & Landi, 2022; Sugimoto & Nagasawa, 2017; Wallner et al., 2020; Zafarmand et al., 2003).	Timeless design is centred on the longevity of a product's appeal and utility within a product's lifespan. Conversely, design–durability ensures that specific design elements are sustained through multiple product cycles and diverse products. Design–durability makes components, interfaces, or aesthetic choices designed to be reusable or adaptable across future products. While timeless design is user– and usage–centric, design–durability also encompasses considerations such as regulatory compliances, industrial evolution, product viability, etc. Timeless design and design–durability philosophies complement each other and help achieve product longevity from user interest and adaptive capabilities needed for future viability.
Slow Design	This strategy helps create visually captivating and emotionally compelling products to lower consumption and extend product lifespans of a product instance (De Hooge et al., 2024; Grosse–Hering et al., 2013).	Slow design promotes slow consumption habits and enhances appreciation. Contrary to design–durability, which emphasises design elements' lasting attractiveness and usefulness, slow design philosophy considers the entire lifespan and influence of products.
Resilient Design	This notion helps prioritise adaptable, robust products that remain functional and valuable amidst environmental, usage, and psychological changes (Haug, 2018).	Resilient design is distinct from design–durability as it focuses on a product's capacity to maintain its functionality and form in challenging circumstances rather than the consistent presence of design features in various product versions.
Style Longevity	This is defined as the preference to purchase and wear clothing to remain relevant and valuable over an extended period, avoiding fast fashion trends (Armstrong & Lang, 2018).	Style longevity is about the enduring appeal and usefulness of fashion items, and design–durability deals with the persistent use of specific design features across various products and their ongoing practical and aesthetic value.

DNA	In the context of product design, DNA is the aesthetic and conceptual framework defining a brand's identity, ensuring consistency and enabling innovation across product families (Eves & Hewitt, 2009; Rahim et al., 2015; Zhaolin Lu et al., 2009; Zuyao Zhang et al., 2009).	DNA in product design helps maintain a brand's identity and coherence of products, while design–durability ensures the continuity of specific design elements across iterations and categories. Design DNA serves as a framework for brand alignment and market positioning. Design–durability focuses on sustainability, user–centric considerations, and features' adaptative capabilities.
Design Continuity	Design continuity ensures seamless integration of visual and functional elements throughout the product design process. This helps maintain brand identity and enhances user experience, efficiency, customer recognition, and loyalty (Althuizen & Chen, 2022; Hsiang et al., 2011; Talke et al., 2017; Yu et al., 2022).	Design–durability broadly makes a feature achieve longevity across various product iterations, whereas design continuity focus is narrower to maintain consistency within a single product's development cycle.

Design-durability emphasises the long-lasting nature of design features, and circular design adopts a holistic approach to sustainability, which are complementary strategies. Collectively, they address diverse sustainability aspects and mitigate environmental harm. By incorporating these principles, it is possible to generate groundbreaking solutions that align with consumers' expectations and ecological sustainability goals.

Table 4 Comparative analysis of design–durability and related concepts across various forms of longevity

		Various Longevity		
Concepts	Attributes	Long product life	Long product use	Market endurance
Physical Durability	Materialisation	X		
	Feature			
	Style			
	Product Model			
	Product Instance	X		
Emotional Durability	Materialisation	X	X	
	Feature			
	Style			
	Product Model			
	Product Instance	X	X	
Psychological Durability	Materialisation			
	Feature			
	Style	X		
	Product Model	X		
	Product Instance			
Strategic durability	Materialisation	X		
	Feature			
	Style			
	Product Model			
	Product Instance	X		
Design–Durability	Materialisation			
	Feature			X

	Style			X
	Product Model			X
	Product Instance			
Timeless design	Materialisation	X	X	
	Feature		X	X
	Style		X	X
	Product Model		X	X
	Product Instance			
Slow design	Materialisation	X		
	Feature	X	X	
	Style		X	
	Product Model		X	
	Product Instance		X	
Resilient design	Materialisation	X	X	
	Feature		X	
	Style		X	
	Product Model		X	
	Product Instance	X	X	
Style longevity	Materialisation			
	Feature			X
	Style			X
	Product Model			
	Product Instance			
DNA	Materialisation			
	Feature			X
	Style			X
	Product Model			
	Product Instance			
Design Continuity	Materialisation			
	Feature			X
	Style			X
	Product Model			X
	Product Instance			

Based on the concepts defined in Table 3, Table 4 attempts to map different durability concepts similar or overlapping to design-durability, illustrating their contribution to longevity based on materialisation, features, style, product model, and product instance. These attributes have been observed as key factors in achieving various forms of longevity. Materialisation addresses the physical interactions a product undergoes; features concern with specific characteristics or functions incorporated in a product; style concerns the aesthetic and visual aspects of the product design; product model refers to the variant of a product that is positioned in the market from a product type; and product Instance refers to the product owned by the consumer:

a. Long-product life refers to the physical survival of the product over an extended period. Based on the concepts defined in Table 3, physical durability, emotional durability, strategic durability and resilient design contribute to this longevity based on materialisation, which concerns the product's physical interactions of the product and is associated with a single product instance.

b. Long-product use involves consumers extending a product's usage beyond its typical lifecycle in various ways. Emotional durability increases a product's usage lifespan by fostering emotional bonds with the user. This concept focuses on individual product instances to achieve long-term product usage. Psychological durability ensures continued relevance with the user by incorporating famous product features and styles. Timeless design also contributes to prolonged product use in product models by providing features and styles that can withstand changing trends. Timeless design helps make a design more relevant and valuable to the user. Slow design extends the usage span of a product through materialisation, which allows the product to withstand aggression by keeping itself relevant to the user psychologically and forming an emotional bond by providing timeless features and styles. Resilient design extends the product usage span by providing it with the ability to withstand and recover from physical, environmental, and social stresses. This notion deals with increasing product life and usage life through various ways.

c. Market endurance refers to making the design lasting in the market across various timelines. Design-durability contributes to market endurance by offering adaptive features and styles applicable to multiple products. It specifically deals on the level of product models instead of instances. In contrast, timeless design helps a product model achieve an enduring presence in the market by providing features and styles that can transcend the trends and remain valuable. Product DNA facilitates the creation of product features and styles that are representative of the brand's identity and continue to exist in the market. Product DNA aims not to develop a specific model but to cultivate enduring brand characteristics. Meanwhile, design continuity ensures consistency in design elements and branding across related products of a manufacturer or a product line.

4. 2. Practical Implication

Design-durability is a new approach to product design that emphasises design elements' lasting relevance over multiple product iterations and timeframes. It moves away from solely focusing on individual products' durability or emotional attachment. This approach necessitates a comprehensive perspective on product development, compelling designers to investigate and foresee the future needs of users and the advancement of technology to guarantee the durability of design elements. It promotes the creation of easily updateable, repairable, or repurposable products by incorporating adaptive features and standardised elements that support sustainability and circular economy goals. This approach reduces waste and encourages resource recycling. Furthermore, design-durability focuses on maintaining user interest and loyalty by prioritising features with long-lasting appeal, thus addressing the issue of becoming outdated. In essence, design-durability offers a new outlook for designers and manufacturers looking to improve the sustainability of their products,

increase user involvement, and promote more sustainable consumption and production patterns.

5. Conclusion

The comprehensive literature review on product durability explores the intricate relationship between durability and various elements of the product lifecycle. The review categorises durability into four categories - physical, psychological, emotional, and strategic, and maps their interplay with various forms of obsolescence. The analysis revealed intricate relationships between these durability types and product life cycles, highlighting how they counteract different obsolescence mechanisms.

The study advocates for a multi-faceted approach to product design and consumption, promoting the adoption of resilient, slow, timeless, emotionally, and psychologically durable design principles. These strategies aim to extend products' physical and emotional lifespans and address broader sustainability challenges by promoting circular economy practices. Such approaches encourage the reuse and optimisation of product utility, thereby reducing environmental impacts and fostering sustainable consumption patterns.

Moreover, the literature review on product durability helped define the gap that exists in the literature and introduced the concept of design-durability, emphasising the need for designers to prioritise the long-term viability of design elements across multiple product iterations, thus promoting sustainable production and consumption patterns.

The study presents a literature review to comprehensively understand product durability, particularly focusing on obsolescence and sustainable product design strategies. While performing keyword-based analysis, the threshold might have effectively optimised the results by reducing noise; it may have also excluded some potentially interesting findings. The study predominantly utilises qualitative analysis of literature to gain insights into the longevity and obsolescence of products. The study's limitations hinder the quantitative validation of the proposed strategies' effectiveness in prolonging product lifespans and reducing obsolescence. In order to improve research in this domain, it would be beneficial to carry out empirical studies and quantitative assessments to confirm and improve these strategies.

The study introduces the novel concept of design-durability and provides preliminary insights into this new phenomenon. Although the concept has been outlined, it is still in its preliminary phase. A comprehensive exploration and investigation are required to comprehend ways of achieving design-durability and its implications and to optimise its integration into product design and development processes. By aligning these durability strategies with sustainable and circular economic models, companies can enhance product longevity, improve market competitiveness, and ensure compliance with environmental standards, thus contributing to a more sustainable future.

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Appendices:

Appendix A: Additional statistical data

〈Table A.1〉 Clusters and respected literature

Name of the cluster	References
Sustainable Product Design and Durability	(Agrawal et al., 2016; Ahmad et al., 2018; Aldridge, 2004; Alev et al., 2020; Alfieri et al., 2018; Almanzar Gomez & Bussracumpakorn, 2014; Aziz et al., 2021; Bakker et al., 2014; J. Chapman, 2016a; J. A. Chapman, 2008; Chen & Turpault, 2021; Den Hollander et al., 2017, 2017; Ghimouz et al., 2023; Goering, 1997; Guiltinan, 2009; Gulden et al., 2010; Haines-Gadd et al., 2017, 2018; Haug, 2018; Huang et al., 2019; Hunkeler & Vanakari, 2000; Jensen, Haase, et al., 2021; Ji & Lin, 2022; Khosla, 2021; Kinokuni et al., 2019; Lobos & Babbitt, 2013; Løvbak Berg & Hebrok, 2024; Madge, 1997; Maitre-Ekern, 2021; Mont, 2008; Mulet et al., 2022; Munten et al., 2021; Munten & Vanhamme, 2023; Nazzal et al., 2013, 2013; Nicolás et al., 2019; Okumura et al., 2001; Ossevoort, 2010; Pradish Kumar & Shanthi Imaculate Jaculin, 2023; Proske et al., 2016; Rahimifard et al., n.d.; Razeghian & Weber, 2019; Schifferstein & Zwartkruis-Pelgrim, 2008; Sellitto et al., 2017; Sierra-Fontalvo et al., 2023; Skuba & Suyetin, 2019; Sun et al., 2021; Van Krieken et al., 2012; Van Nes & Cramer, 2005; Vanacker et al., 2022; Willskytt & Brambila-Macias, 2020; Xiong et al., 2012)
Circular economy and sustainable design strategy	(Agrawal et al., 2016; Ahmad et al., 2018; Alfieri et al., 2018; Almanzar Gomez & Bussracumpakorn, 2014; Alqahtani & Gupta, 2017; Aziz et al., 2021; Bakker et al., 2014; Bocken et al., 2016; Boorsma et al., 2022; Carlsson et al., 2021; J. Chapman, 2015, 2016a, 2016b; J. A. Chapman, 2008; Chen & Turpault, 2021; Cooper, 1994, 2005, 2016; Cordella et al., 2021; Coscieme et al., 2022; Creusen et al., 2010; Cseke et al., 2020; Den Hollander et al., 2017; Frahm et al., 2022; Fuchs & Hovemann, 2022; Guiltinan, 2009; Gulden et al., 2010; Haase & Lythje, 2022; Habibollahi Najaf Abadi et al., 2023; Hagedorn et al., 2017; Haines-Gadd, 2019; Haines-Gadd et al., 2017, 2018; Hasling & Ræbild, 2017; Haug, 2019; Hebrok, 2014; Huang et al., 2023; Hunkeler & Vanakari, 2000; Jensen, Laursen, et al., 2021; Ji & Lin, 2022; Khosla, 2021; Kinokuni et al., 2019; Ko, 2017; Lacey, 2009; Løvbak Berg & Hebrok, 2024; Maitre-Ekern, 2021; Mesa et al., 2022; Mestre & Cooper, 2017; Mont, 2008; Moreno et al., 2016; Mugge et al., 2008; Mulet et al., 2022; Nyström, 2019; Okumura et al., 2001; Pradish Kumar & Shanthi Imaculate Jaculin, 2023; Selvefors et al., 2019; Shin et al., 2021; Sonego et al., 2018; Suppipat & Hu, 2022; Van Dam et al., 2020; Van Krieken et al., 2012; Van Nes & Cramer, 2005; Van Weenen, 1995; Vermunt et al., 2019; Virtanen et al., 2017; Walter, 2016; Willskytt & Brambila-Macias, 2020; Wu et al., 2021)
Sustainable product design and lifecycle management	(Agrawal et al., 2016; Ahmad et al., 2018; Aldridge, 2004; Alfieri et al., 2018; Ardente & Mathieux, 2014; Bahmed et al., 2005; Bakker et al., 2014; Blijlevens et al., 2009; Boyle et al., 2018; Ceschin & Gaziulusoy, 2016; J. Chapman, 2009, 2016a, 2016b; Cooper, 2005; Cordella et al., 2021; Cseke et al., 2020; Den Hollander et al., 2017; Eichner & Runkel, 2003; Ghimouz et al., 2023; Habibollahi Najaf Abadi et al., 2023; Haines-Gadd, 2019; Haines-Gadd et al., 2017; Haug, 2018; Huang et al., 2019, 2023; Hunkeler & Vanakari, 2000; Jensen, Haase, et al., 2021; Jensen, Laursen, et al., 2021; Ji & Lin, 2022; Khosla, 2021; Kinokuni et al., 2019; Løvbak Berg & Hebrok, 2024; Mesa et al., 2022; Mittelman et al., 2020; Mulet et al., 2022; Munten et al., 2021; Okumura et al., 2001; Ossevoort, 2010; Razeghian & Weber, 2019; Sellitto et al., 2017; Selvefors et al., 2019; Sierra-Fontalvo et al., 2023; Sonego et al., 2018; Strandbakken, 2009; Sun et al., 2021; Suppipat & Hu, 2022; Thornquist, 2017; Van Krieken et al., 2012; Van Nes & Cramer, 2005; Van Weenen, 1995; Vanacker et al., 2022; Wiecek et al., 2019; Wieser, 2017; Willskytt & Brambila-Macias, 2020; Xiong et al., 2012)
Sustainable decision making and environment impact assessment	(Almanzar Gomez & Bussracumpakorn, 2014; Boorsma et al., 2022; Braungart et al., 2007; Ceschin & Gaziulusoy, 2016; J. Chapman, 2016b; J. A. Chapman, 2008; Cupchik, 2017; Den Hollander et al., 2017; Fossdal & Berg, 2016; Haines-Gadd, 2019; Haines-Gadd et al., 2017, 2018; Haug, 2018, 2019; Huang et al., 2023; Ji & Lin, 2022; Khosla, 2021, 2021; Ko, 2017; Lacey, 2009; Lobos, 2014; Løvbak Berg & Hebrok, 2024; Nicolás et al., 2019; Sweet & Caudwell, 2017; Thornquist, 2017; Van Dam et al., 2020; Van Krieken et al., 2012; Vanacker et al., 2022; Walker, 1995; Wu et al., 2021)
Emotion-Driven Sustainable design	(Aldridge, 2004, 2004; Almanzar Gomez & Bussracumpakorn, 2014; Alzaydi, 2024; Aziz et al., 2021; Bocken et al., 2016; Boorsma et al., 2022; Carlsson et al., 2021; Ceschin & Gaziulusoy, 2016; J. Chapman, 2009, 2016a; Chen & Turpault, 2021; Cooper, 2016; Coscieme et al., 2022; Den Hollander et al., 2017, 2017; Fossdal & Berg, 2016; Frahm et al., 2022; Fuchs & Hovemann, 2022; Guiltinan, 2009; Guru et al., 2024; Haase & Lythje, 2022; Habibollahi Najaf Abadi et al., 2023; Hagedorn et al., 2017; Haines-Gadd et al., 2017; Harper, 2018; Hasling & Ræbild, 2017; Haug, 2018; Haug & Busch, 2016; Huang et al., 2019, 2023; Hunkeler & Vanakari, 2000; Jensen, Laursen, et al., 2021; Ji & Lin, 2022; Khosla, 2021; Kowalski & Yoon, 2022; Lobos, 2014; Mesa et al., 2022; Mestre & Cooper, 2017; Moreno et al., 2016; Mugge et al., 2005; Munten et al., 2021; Odom et al., 2009; Ossevoort, 2010; Page, 2014; Porter, 2004; Schifferstein & Zwartkruis-Pelgrim, 2008; Shin et al., 2021; Sierra-Fontalvo et al., 2023; Sonego et al., 2018, 2018; Strandbakken, 2009; Sun et al., 2021; Suppipat & Hu, 2022; Thornquist, 2017; Van Dam et al., 2020; Van Krieken et al., 2012; Wu et al., 2021)