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Research on the application of colour-changing materials in smart packaging design: Forms, functions, and innovations

Guanxing Xia
Postgraduate Student
Kyiv National University of Technologies and Design
01011, 2 Mala Shyianovska Str., Kyiv, Ukraine
Shanxi University of Science and Technology
710021, 6 Xuefu Road, Xi'an, China
https://orcid.org/0009-0001-2322-2939

Nataliia Chuprina*
Doctor of Study of Art, Professor
Kyiv National University of Technologies and Design
01011, 2 Mala Shyianovska Str., Kyiv, Ukraine
https://orcid.org/0000-0002-5209-3400

Abstract. The relevance of the research stemmed from the positive role that colour-changing materials played in smart packaging design. It not only addressed consumers' demand for interactive packaging experiences but also enhanced the additional value of packaging design. The purpose of this study was to explore the current applications and development trends of colour-changing materials in smart packaging design. It was investigated how these materials can be used to convey product information, improve user experience, and increase the functional value of packaging. This study employed the following methods: literary and empirical analysis. Case study analysis and visual analysis methods were applied to examine visual effects. The research systematically analysed how different brands (Anrealage, Disney, Phillips Distilling, Maeil Milk, Leaf Bandage, Warm Me, McDonald's, Yuan Qi Forest, Coors Light, Naked, Coca-Cola, Lipton, Monster Party) utilised colour-changing materials in their packaging designs and the visual effects achieved. The synergistic innovation space of colour-changing materials in smart packaging design was confirmed. The study revealed that most brands' smart packaging employed two types of materials: photochromic and thermochromic. These materials exhibited reversible colour changes under external stimuli, which enabled real-time visualisation of product quality, temperature variations, and anti-counterfeiting verification. It generated visual signalling, enhanced brand differentiation, and transformed conventional packaging design. Furthermore, the research also identified a new method that supports customisable colour-changing materials, which provided both theoretical and practical advancements in this field. The practical significance of this study lies in the application of colour-changing materials in smart packaging design, which enhances the entertainment value and interactive function of packaging, and will contribute to the market competitiveness of packaging products and the development of the industry

Keywords: visual impact; visual design; responsive surfaces; user experience; colour visualisation

INTRODUCTION

Packaging, as one of the most frequently encountered elements in daily life, is undergoing a profound functional paradigm shift. According to A.P. D'Almeida & T.L. de Albuquerque (2024), driven by both consumption upgrading and technological advancement, packaging design has transcended its traditional roles of product protection and visual communication, evolving from static containers to intelligent interfaces. As an innovative paradigm in packaging design, smart packaging integrates advanced materials and technologies

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*Corresponding author

to endow packaging with smart features such as sensing, responding, and interacting, thereby reshaping the relationship between products and consumers. This is particularly relevant, as consumers increasingly seek interactive and personalised experiences, making the exploration of intelligent, responsive packaging solutions both timely and necessary.

Packaging design has evolved from a traditional dual focus on aesthetics and functionality to a multidimensional research field encompassing market dynamics, consumer behaviour, and technological innovation. Against the backdrop of rapid advancements in material science and information technology, packaging trends during this period exhibited growing characteristics of intelligence and interactivity. However, J. Lydekaityte & T. Tambo (2020) pointed out that smart packaging was not merely a physical container, but functioned as an intermediary between digital and physical product management, bridging the stages from packaging design to market sales. This perspective complemented the attributes of smart packaging design. In applied research, E. Drago *et al.* (2020) used a systematic analytical approach to explore the multiple functions of smart packaging in the food industry, including food safety monitoring, preservation technologies, enhanced information interaction, and improved consumer perception. Meanwhile, according to the empirical research by L. Du *et al.* (2025), smart materials and Internet of Things (IoT) technology were able to regulate food storage environments in real time. Their research demonstrated the practical application benefits brought by smart packaging design. Both studies showed that smart packaging technology held promise in improving food quality, extending shelf life, and optimising communication mechanisms between consumers and products through real-time data feedback.

D. Elkhattat & M. Medhat (2021), from the perspectives of brand communication and user experience, emphasised that smart packaging should serve as a vital medium for brand emotional expression and consumer interaction, thus expanding the semantic space of packaging design. This perspective received further validation by I. Gigauri *et al.* (2024), who employed a questionnaire survey method to collect data on consumers' cognition, attitudes, and purchase intentions toward branded smart packaging. The study combined these findings with descriptive statistical analysis to identify key influencing factors. Results demonstrated that consumers exhibited high interest in smart packaging technologies and expressed positive attitudes toward brands adopting such designs. The perspectives complemented each other. They provided insights into the positive role that smart packaging design played in brand communication value. Smart packaging materials emerged as the key technological support and a 21st-century research focal point, with their functionality and design potential driving significant attention. A. Ozcan (2020) demonstrated that the integration of materials and their technological expression played a fundamental role in smart packaging design innovation. Y. Su *et al.* (2020), through bibliometric analysis, categorised smart packaging materials into three types based on their working principles: functional materials, structural materials, and information-sensing materials, and provided a theoretical foundation for the classification system of smart packaging materials.

In specific research on colour-changing materials, S. Mahović Poljaček *et al.* (2024) constructed a photosensitive colour-changing packaging system based on the principle of photochromism through experimental methods. These materials changed colour in response to different wavelengths or intensities of light, thus conveying product information or environmental conditions with a highly visible effect. N. Mergu & Y.A. Son (2021) used comparative analysis to study the response mechanism of thermochromic packaging, systematically reviewed the development of organic, inorganic, liquid crystal, and polymer thermal-sensitive materials since thermochromic coatings were first developed in Germany in 1983. Their findings suggested that thermochromic materials change colour with temperature variations by altering their absorption rate of visible light. According to a study by Y. Zhou & R. Guo (2024), the gas-sensitive colour-changing packaging developed by the Japanese TO-Genkyo studio further extended the perceptive dimension of smart packaging, allowing it to indicate the freshness, ripeness, or gas leakage of food through spatial changes in gas composition, which offered significant practical value in food packaging design. These researchers have expounded and conducted experiments on colour-changing packaging design materials from the aspects of photochromism, thermochromism, and gas chromism.

Different scholars have validated the practical effectiveness of colour-changing materials through specific experimental results, yet further exploration is needed regarding their application in various types of packaging design. The purpose of this study was to analyse material applications and design methodologies, with a particular focus on photochromic and thermochromic materials. The research examined their visual impact, user experience, and creative expression.

MATERIALS AND METHODS

This study employed multiple methods to investigate the application of colour-changing materials in smart packaging design. On the one hand, the literature review method was utilised to examine scientific publications and industry reports related to colour-changing materials and smart packaging design from 2018 to 2025. This approach helped to identify the current research landscape, existing achievements, and unresolved challenges, thereby pinpointed potential research entry points and innovative areas. Through

academic databases such as Web of Science and Scopus, high-impact-factor journals were prioritised for analysis, which enabled the systematic organisation and synthesis of relevant literature to extract valuable insights and perspectives. Particular emphasis was placed on elucidating the intrinsic relationships among material properties, morphological expressions, and functional implementations of photochromic, thermochromic, and other smart materials.

On the other hand, the case study method was adopted to conduct in-depth analyses of smart packaging designs incorporating colour-changing materials. This approach served as a practical foundation for summarising design principles while identifying real-world application challenges and proposing targeted improvement measures. Case selection was based on three core criteria: innovation, user experience, and commercial value. These indicators respectively corresponded to the visual effect of packaging, consumer perception, and market performance, thus comprehensively covering the three key dimensions of product, user, and market. To ensure representativeness, the study examined smart packaging cases from prominent brands, including Anrealage (Trinera, 2023), Disney (The Disney case, n.d.), Phillips Distilling (Packaging machinery automation, 2022), Maeil Milk (Red Dot, 2021), Leaf Bandage (Yankodesign, 2016), Warm Me (Freeman, 2015), McDonald's (Baidu, 2024), Yuan Qi Forest (Jinjia, 2022), Coors Light (2017), Naked (Beijing Zhiyoumai Technology, 2015), Coca-Cola (Shineray, 2018), Lipton (Packaging manager, 2017), Monster Party (Bloclo, n.d.). Each case was analysed in terms of packaging design characteristics, types and application methods of colour-changing materials employed, the functional realisation of the packaging, market feedback, and consumer evaluations. In the specific analysis, a visual analysis approach was further applied to assess colour performance and visual impact across different smart packaging designs. Additionally, during the research process, supplementary data from professional information websites were incorporated. These data were primarily sourced from market research institution (Food and Beverage Innovation report, 2024) and image websites, and provided updated sample references for the study. The reliability and accuracy of these sources were rigorously evaluated to ensure data quality and credibility throughout the investigation. By integrating these methods, this study ensured a robust, multi-dimensional investigation into the application of colour-changing materials in smart packaging design.

RESULTS AND DISCUSSION

At the forefront of smart packaging design, colour-changing materials redefined the sensory dimensions of product packaging through their exceptional environmental responsiveness and dynamic visual interaction capabilities. This breakthrough not only accelerated the intelligent transformation of packaging as a medium but also served as a core driver of technological innovation in the industry. By analysing the working principles and performance characteristics of different types of colour-changing materials, the study explored integration strategies for visual communication. Case studies summarised how these materials enhanced packaging functionality, improved user experience, and created brand value, providing theoretical references and practical guidance for designers and packaging engineers. Additionally, the study identified technical challenges and future innovation directions in the application of colour-changing materials, which offered insights to promote the development of smart packaging industries.

Forms and functions of colour-changing materials in smart packaging design. Previous studies have established an important theoretical foundation for understanding smart packaging design. A. Azzi *et al.* (2012), through a structured literature review, proposed a multidimensional research framework that includes product features, market environment, and user needs, which marked a shift from traditional formalism to a systemic, user-centred approach. D. Schaefer & W.M. Cheung (2018) further analysed this view through case studies and theoretical induction, focusing on the concept, application prospects, and major challenges of smart packaging. They highlighted its potential to enhance user experience, improve product monitoring and tracking, and optimise supply chain management. However, their research was biased towards smart technologies such as sensors, Radio Frequency Identification (RFID), and the Internet of Things, overlooking the role that colour-changing materials play in smart packaging. This study designed a chart of the discovered results and the classification of colour-changing materials and the functions each material can achieve (Fig. 1). In addition, this study identified recent industry trends toward customisable smart packaging solutions that incorporate colour-changing materials, enable brands to tailor interactive effects to specific products and target audiences. While C. Liu *et al.* (2019) recognised the technical maturity and potential applications of these materials, which aligned with the author's findings. But the current research further explored their integration into practical packaging design and highlighted their role in enhancing user experience and brand value. Despite challenges related to durability and cost, colour-changing materials offered an accessible, visually engaging pathway for advancing smart packaging beyond electronic solutions. Building on this academic context, the present research systematically examined and categorised the forms and functions of colour-changing materials in smart packaging design. Specifically, photochromic materials changed

colour under light exposure served anti-counterfeiting purposes and enriched visual perception by providing dynamic feedback. Thermochromic materials reacted to temperature fluctuations, thereby supported brand communication, indicating temperature and freshness, and created interactive sensory experiences. Gas-sensitive materials responded to variations in gas concentrations, allowing real-time freshness monitoring and enhancing consumer trust. These materials, through their inherent environmental responsiveness, transformed packaging into an interactive medium that communicated directly with users.

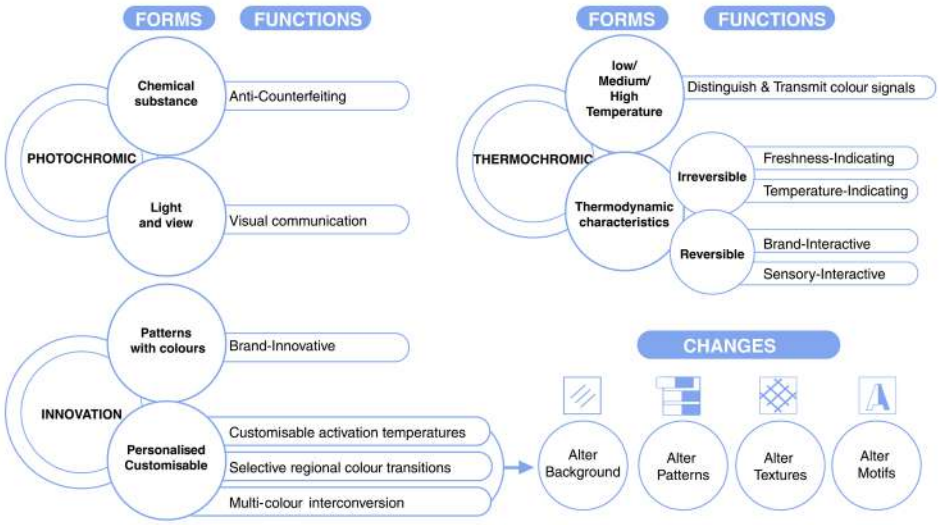

Figure 1. Forms, functions, and innovation of colour-changing materials
Source: completed by the authors' research

Opportunities for photochromism in the context of smart packaging design. According to the research overview of photochromic materials by P. Cheng *et al.* (2024), Photochromism refers to the reversible colour change exhibited by certain chemical substances upon exposure to optical radiation. This phenomenon involves a structural isomerisation transition at the molecular level, manifesting as a pronounced shift in absorption spectra. According to X. Xu & R. Huang (2025) research, in the ground state of photochromism, substance A undergoes a photochemical reaction under specific wavelengths, converting to the excited state substance B. After cessation of irradiation, substance B reverts to substance A's original form and colour, achieving reversible chromatic transformation. For instance, at the Winter 2023 Paris Fashion Week, the Japanese brand ANREALAGE showcased a ground-breaking material experiment (Fig. 2). Designer Kunihiko Morinaga innovatively employed photochromic technology to transform monochromatic white garments into dynamic colour carriers. When exposed to specific wavelengths of ultraviolet light, the minimalist fabric surfaces instantaneously revealed intricate patterns. This real-time visual transformation challenged the static nature of conventional textiles and redefined the interactive relationship between wearers and their environment. Through the innovative application of materials science, the project demonstrated new possibilities for functional aesthetics.

Figure 2. Photochromic clothing design for the Winter 2023 Paris Fashion Week
Source: P. Trinera (2023)

Currently, photochromism is primarily applied in packaging design for two purposes: as an advanced anti-counterfeiting visual identifier, and to create smart packaging with visual interactivity. As the viewing angle or lighting conditions change, these materials exhibit colour shifts, thereby enabling anti-counterfeiting functionality. For example, the product labels at Shanghai Disney Resort incorporated photochromic materials to create a multi-layered dynamic visual

presentation through precise photochromic effects (Fig. 3). In their default state, the labels display castle motifs and the brand logo. When the viewing angle or lighting conditions alter, the labels dynamically reveal a visual effect of fireworks in motion. Simultaneously, variations in the viewing angle allow observers to perceive changes in the fireworks' colours, along with the gradual emergence of hidden microscopic details such as the "Disney" lettering. This dynamic authentication mechanism, based on optical properties, not only enhances the reliability of anti-counterfeiting technology and user interaction but also strengthens brand recognition through narrative-driven visual language. According to the findings of J. Wan *et al.* (2023), the application of photochromic materials has demonstrated great brand value in anti-counterfeiting and information security, Meanwhile, according to F.R. Zang (2021), photochromic materials can produce strong visual attraction by combining with logo of package design, which is conducive to brand communication.

Figure 3. Shanghai Disneyland photochromic anti-counterfeiting packaging design
Source: The Disney case (n.d.)

The photochromic packaging design introduced by Phillips Distilling in 2021 redefined the interactive paradigm of spirits packaging (Fig. 4). Grounded in the core concept of "Bring the Light", this design integrated the properties of photochromic materials with innovative packaging strategies, establishing a dynamic interaction between the product and environmental sunlight. By leveraging photochromic materials, the packaging undergoes real-time spectral shifts upon exposure to ultraviolet light. Initially appearing black and colourless at the bottleneck, concealed chromatic lettering gradually emerges under ultraviolet activation, extending axially toward the main label area. Upon removal from light, the colours fade, while the black "UV" brand outlines remain visible, thereby creating a dual mechanism that combines transient aesthetic engagement with persistent brand recognition.

Figure 4. Phillips Distilling Company "bring the light" colour-changing vodka packaging design
Source: Packaging machinery automation (2022)

Photochromic materials demonstrated dual breakthroughs in smart packaging design through their dynamic light-responsive properties: they revolutionised anti-counterfeiting systems while reconstructing user interaction paradigms. The technology simultaneously addressed security authentication and experience optimisation needs via real-time visual feedback mechanisms, with commercial brand applications confirming its significant efficacy in enhancing product value.

Application of thermochromism in smart packaging design. Thermochromism refers to the phenomenon where a material changes colour in response to temperature variations, thereby indicating temperature changes through colour shifts. According to the research by J. Chen *et al.* (2024), thermochromic materials can be classified in two ways: based on their temperature range or their thermodynamic properties. According to the temperature range, thermochromic

materials are categorised into three types: low, medium, and high-temperature variants. High-temperature thermochromic materials typically exhibit red hues, medium-temperature ones appear orange, while low-temperature materials display blue hues. Based on their thermodynamic characteristics, thermochromic materials are further divided into two types: irreversible and reversible. Irreversible thermochromic materials undergo permanent colour changes that cannot be reversed. In contrast, reversible thermochromic materials can undergo multiple colour changes in response to temperature fluctuations. These properties determined their applications: irreversible types for safety monitoring, while reversible types enable dynamic interaction. Meanwhile, according to the research findings of C. Breheny *et al.* (2024) in the specific smart packaging design of food, irreversible thermochromic materials rely on thermal decomposition or oxidation reactions to record one-time temperature events, making them suitable for monitoring freshness or indicating temperature breaches in safety-critical packaging.

Dairy company Maeil Milk developed a smart milk packaging system integrated with irreversible thermochromic ink to visually indicate product freshness (Fig. 5, a). The packaging featured a gradual colour transition, where the blue "milk" label progressively fades as the product approaches expiration, ultimately transforming into the warning word "ill". This innovative design visually tracked freshness while conveying safety warnings through semantic transformation, demonstrating smart packaging's potential for effective information delivery. Similarly, irreversible thermochromic inks not only offered functionality but also provided users with an aesthetic experience. The "Leaf Bandage" served as an example (Fig. 5, b), the Leaf Bandage utilises thermochromic ink, with its packaging gradually shifting from green to yellow and finally dark yellow over time. This colour change visually indicates product expiration. In terms of form design, a bionic approach is adopted, where the leaf-shaped design language not only fulfils functional requirements but also endows the product with distinctive emotional value, exemplifying the human-centric characteristics of packaging design.

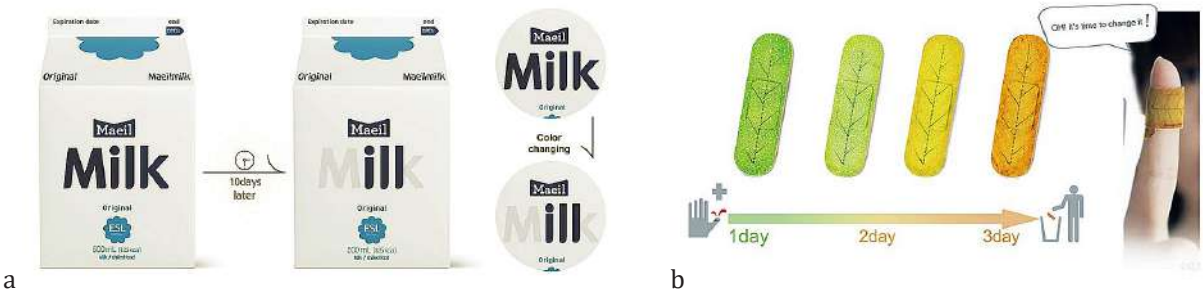

Figure 5. Freshness-indicating thermochromic packaging design
Note: a – Maeil Milk thermochromic smart packaging design; b – Leaf Bandage colour-changing smart packaging design
Source: Yankodesign (2016), Red Dot (2021)

Reversible thermochromic inks have demonstrated significant potential in dynamic visual interaction and brand communication, a finding corroborated by Q. Li *et al.* (2024). Their research argued that these materials could enhance product originality and aesthetic appeal in food packaging applications, which increased consumer engagement and purchase intention through improved visual interactivity and personalisation. This is consistent with the conclusion drawn by L. Spytska (2024), who noted that consumers are more likely to respond positively to products with emotionally appealing design elements that evoke joy, comfort, or pleasant memories, thereby reinforcing the effectiveness of visually innovative packaging. According to the Food and Beverage Innovation report (2024), the official Instagram account of McDonald's Singapore posted a thermochromic packaging design on January 10, 2024, received 153,000 likes – a figure that was a hundred times higher than its average post engagement, sparking widespread discussion among global internet users. This design employs advanced reversible thermochromic ink technology: when filled with iced water, the originally metallic silver aluminium cup undergoes an instantaneous colour transformation, gradually transitioning into a refreshing green hue (Fig. 6, a). It exemplifies the seamless integration of colour-changing materials with packaging visual aesthetics. Another example is the Chinese brand "Yuan Qi Forest", which introduced an innovative "blossoming" sakura packaging design for its sparkling water (Fig. 6, b), utilising reversible thermochromic materials. When the product temperature dropped below 8°C, the cherry blossom patterns on the packaging, originally in bud form, undergo a phase-change colour transition, unfolded into a fully bloomed petal display. This created a temperature-responsive visual interaction that integrates material properties, seasonal imagery, and consumption scenarios, demonstrated the brand's pioneering exploration in smart packaging design. Similarly, Coors Light revolutionised its packaging with

temperature-sensitive "Rocky Mountains" graphics (Fig. 6, c). At a simple temperature, the mountain outlines appear faint and grey, but when chilled below 4.5°C, the contours gradually sharpen and fill with a progressive blue hue. This visual transformation effectively evokes consumers' association with the beer's refreshing coolness, achieving a precise translation of product characteristics into a user experience.

Figure 6. Thermochromic smart packaging design series
Note: a – McDonald's thermochromic packaging design; b – Yuan Qi forest thermochromic sparkling water packaging design; c – Coors Light thermochromic beer packaging design
Source: Coors Light (2017), G. Jinjia (2022), Baidu (2024)

The yoghurt brand "Warm Me" utilised thermochromic ink to create dynamic packaging visuals that responded to temperature changes (Fig. 7). Below 20°C, the packaging displayed a dormant penguin; between 21-24°C, the penguin's eyes gradually opened, and signalled the ideal eating temperature. This material-driven interaction not only provided functional guidance but also enhanced user experience by translating design concerns into emotional connections.

Figure 7. "Warm Me" thermochromic yoghurt smart packaging design
Source: E. Freeman (2015)

In terms of sensory interaction, the cosmetic brand Naked used an innovative mechanism of tactile-visual interaction using reversible thermochromic materials (Fig. 8). When touched, the packaging underwent a blush-like colour shift, mimicking natural skin tones. This biomimetic design seamlessly integrated product functionality with sensory marketing strategies while fostering an emotional connection between users and the packaging. Through the application of this approach, the brand established a distinct competitive edge in the market through differentiated packaging innovation. Thermochromic materials offered dual smart packaging benefits: irreversible types provided safety monitoring through permanent colour changes, while reversible variants enabled interactive user experiences and brand communication. Collectively, they transformed packaging from passive containers to interactive media. The research found that this technology bridged product functionality, user engagement, and commercial value through visual communication, marking smart packaging's transition to industrial-scale adoption.

Figure 8. Packaging design of Naked thermochromic sensory interactive cosmetics
Source: Beijing Zhiyoumai Technology (2015)

Innovation of colour-changing materials in smart packaging design. With the advancement of colour-changing materials and smart packaging design, these innovations opened up new expressive dimensions for visual design. The research by Y. Zhu (2024) and S. Ayinuer *et al.* (2021) demonstrated that the dynamic behaviour of colour-changing materials significantly influenced emotional states and shaped perceptions of product attributes. Building on this foundation, the present study found that such effects required deliberate integration with graphic design components to maximise communicative efficacy. Specifically, in thermochromic packaging systems, the synergy between material-driven colour transitions and structured visual motifs enhanced brand distinctiveness, information legibility, and personalised user engagement. For example, the Coca-Cola company introduced a thermochromic packaging design concept for its "Summer" themed collection (Fig. 9, a). This design featured an "ice cube" as the primary visual element, employing thermochromic inks to create a dynamic visual transformation. When the product is chilled, the ice cube patterns on the bottle shifted to a blue hue, accompanied by changes in the visual imagery. This form of combining graphics and colours with colour-changing materials enhances visual expressiveness and information accuracy. Similarly, Lipton launched a limited-edition iced tea could with temperature-responsive properties during Belgium's Electronic Music Festival (Fig. 9, b). When refrigerated to the optimal serving temperature, the originally plain can gradually reveal a vibrant light-blue tint along with the word "LOVE". The brand crafted an interactive slogan, "Chill the Can and See the Love", ingeniously transforming the product usage process into an emotional engagement tool. This innovative approach, which merges packaging functionality with emotional experience, resonated strongly with consumers upon release, delivering a remarkable marketing impact. While delivering the colour and text of the product, it also reinforced the brand image.

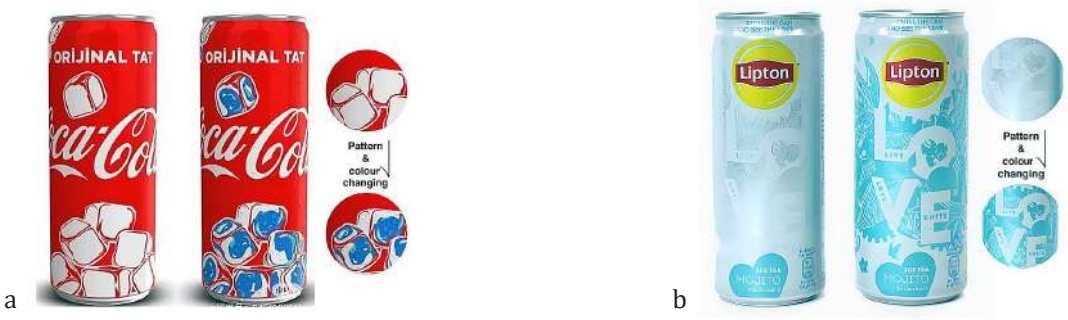

Figure 9. Innovative colour-changing smart packaging design series
Note: a – Coca-Cola colour-changing smart packaging design; b – Lipton "LOVE" theme colour-changing soda smart packaging design
Source: Packaging manager (2017), Shineray (2018)

Through market research with one packaging material supplier – Kunbei Label Printing (Bloclo, n.d.) revealed that contemporary applications of colour-changing materials extended beyond facilitating visual communication between packaging graphics and product attributes in smart packaging systems. Significantly, these materials enabled customisable design solutions that substantially augment the innovative capacity of modern packaging design. Taking beverage packaging as an example, modern thermochromic materials achieved three breakthrough functionalities: customisable activation temperatures, selective regional colour transitions, and multi-colour interconversion. Leveraging these properties, designers could dynamically alter background patterns, textures, decorative motifs, and even brand logo colours (Fig. 10). This colour-changing material application not only redefined interactive packaging experiences but also enhances product value by stimulating consumer curiosity and engagement. In summary, although existing studies have made progress in the classification, functional mechanisms, and experimental approaches of colour-changing materials, there remain certain limitations in research. (1) Methodologically, most researchers have focused on experimental and qualitative analyses to define and experiment with the principles of colour-changing packaging, but there is a lack of exploration of the artistic expression and visual aspects of packaging design. (2) In terms of research content, although theoretical definitions are valuable, studies heavily oriented toward materials and chemistry have diluted the intrinsic meaning of packaging design. (3) In application, while colour-changing materials have established stable systems in the chemical and textile industries, their use in packaging design was still mainly limited to localised indications and labelling functions, with untapped potential for integrating visual language and building emotional experiences. Additionally, the absence of a designer's perspective and specific methods for user involvement calls for further investigation.

Figure 10. Personalised colour-changing smart packaging design
Source: Bloclo (n.d.)

CONCLUSIONS

The current study systematically examined the applications of colour-changing materials in smart packaging design, focusing on their forms, functions, and innovations. The research found that photochromic materials demonstrated dual value in anti-counterfeiting identification and dynamic visual expression. "Disney packaging labels" illustrated how they enhance anti-counterfeiting measures, while Phillips Distilling's photochromic packaging increased purchase intention of customers by 64%. The study analysed reversible and irreversible thermochromic materials and identified their distinct functions. Irreversible thermochromic materials proved effective in information visualisation, such as food freshness monitoring, as demonstrated by the "Maeil Milk" smart packaging design. Reversible thermochromic materials showed significant benefits in enhancing user interaction experience, improving commercial efficiency, and achieving sensory interaction, as seen in the "Coors Light" and "Naked" packaging. Furthermore, the research proposed two innovative applications for colour-changing materials: functional pattern integration balancing aesthetics and human-centred design; and personalised, customisable systems enabling adjustable colour and texture and transition parameters, thus expanded creative possibilities. However, current applications still face limitations, necessitating designers to develop material cognition frameworks that extend beyond visual presentation to focus on the relationship between material properties and user experience. Future research could investigate the technical feasibility and market acceptance of colour-changing materials in various packaging applications. Additionally, studies should investigate the environmental impact and explore the potential for combining these materials with other smart technologies, such as 3D printing and augmented reality, to maximise their benefits in smart packaging solutions.

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CONFLICT OF INTEREST

None.

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Дослідження застосування матеріалів, що змінюють колір, у розумному дизайні упаковки: форми, функції та інновації

Гуаньсін Ся
Аспірант
Київський національний університет технологій та дизайну
01011, вул. Мала Шияновська, 2, м. Київ, Україна
Шеньсійський університет науки і технологій
710021, вул. Сюефу, 6, м. Сіан, Китай
https://orcid.org/0009-0001-2322-2939

Наталія Чупріна
Доктор мистецтвознавства, професор
Київський національний університет технологій та дизайну
01011, вул. Мала Шияновська, 2, м. Київ, Україна
https://orcid.org/0000-0002-5209-3400

Анотація. Актуальність дослідження зумовлена позитивною роллю, яку відіграють матеріали, що змінюють колір, у розумному дизайні упаковки. Вони не лише задовольняють попит споживачів на інтерактивний досвід використання упаковки, але й підвищують додаткову цінність її дизайну. Метою цього дослідження було вивчити сучасне застосування та тенденції розвитку матеріалів, що змінюють колір, у дизайні розумної упаковки. Було досліджено, як ці матеріали можуть бути використані для передачі інформації про продукт, покращення користувацького досвіду та підвищення функціональної цінності упаковки. У цьому дослідженні були використані наступні методи: літературний та емпіричний аналіз. Для вивчення візуальних ефектів було застосовано методи аналізу конкретних ситуацій та візуального аналізу. У дослідженні було систематично проаналізовано, як різні бренди (Anrealage, Disney, Phillips Distilling, Maeil Milk, Leaf Bandage, Warm Me, McDonald's, Yuan Qi Forest, Coors Light, Naked, Coca-Cola, Lipton, Monster Party) використовували матеріали, що змінюють колір, у дизайні упаковки, і які візуальні ефекти були досягнуті. Це підтвердило синергетичний інноваційний простір матеріалів, що змінюють колір, у дизайні розумної упаковки. Дослідження показало, що більшість брендів використовують два типи матеріалів для смарт-упаковки: фотохромні та термохромні. Ці матеріали демонстрували оборотну зміну кольору під впливом зовнішніх подразників, що дозволило в реальному часі візуалізувати якість продукції, температурні коливання та перевіряти на підробку. Це створило візуальну сигналізацію, посилило диференціацію брендів і трансформувало традиційний дизайн упаковки. Крім того, дослідження також визначило новий метод, який підтримує кастомізовані матеріали, що змінюють колір, що забезпечило як теоретичний, так і практичний прогрес у цій галузі. Практична цінність цього дослідження полягає в застосуванні матеріалів, що змінюють колір, у розумному дизайні упаковки, що підвищує розважальну цінність та інтерактивну функцію упаковки, та сприятиме підвищенню ринкової конкурентоспроможності пакувальної продукції та розвитку галузі

Ключові слова: візуальний вплив; візуальний дизайн; адаптивні поверхні; користувацький досвід; кольорова візуалізація