SMART JEWELRY DESIGN, AESTHETICS AND INNOVATION IN THE DIGITAL AGE

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Abstract. This research analyzes the integration of smart jewelry, which combines fashion with technology, meeting the functional and aesthetic requirements of the 21st century. These advanced accessories, equipped with features such as health monitoring and Bluetooth/NFC connectivity, require a multidisciplinary approach in the design process. The study emphasizes the balance between aesthetic appeal and utility, highlighting the use of recyclable materials and classifying jewelry into four distinct categories, each with specific advantages and challenges. It also investigates the impact of emerging technologies on jewelry design and current trends, demonstrating how these innovations are transforming the accessories industry. Relevant examples from renowned jewelers and companies are presented to illustrate sophisticated designs and wireless interactions. Additionally, innovations such as the StreetSmart app and the Project BLAID device highlight their contribution to the mobility of individuals with visual impairments. In conclusion, smart jewelry represents a significant expression of contemporary trends in fashion and technology, offering new opportunities for IoT connectivity and design flexibility.

Keywords: *smart jewelry, innovation, design of adornments/jewelry, contemporary jewelry, function.*

Rezumat. Această cercetare analizează integrarea bijuteriilor inteligente, care combină moda cu tehnologia, îndeplinind cerințele de funcționalitate și estetică în sec. XXI. Aceste accesorii avansate, dotate cu funcții precum monitorizarea sănătății și conectivitatea Bluetooth/NFC, necesită o abordare multidisciplinară în procesul de design. Studiul subliniază echilibrul între aspectul estetic și utilitate, evidențiind utilizarea materialelor reciclabile și clasificarea bijuteriilor în patru categorii distincte, fiecare având avantaje și provocări specifice. De asemenea, se investighează impactul tehnologiilor emergente asupra designului bijuteriilor și tendințele actuale, demonstrând modul în care aceste inovații transformă industria accesoriilor. Exemple relevante din rândul bijutierilor și companiilor de renume sunt prezentate pentru a ilustra designurile sofisticate și interacțiunile wireless. În plus, inovații precum aplicația StreetSmart și dispozitivul Project BLAID subliniază contribuția acestora la mobilitatea persoanelor cu deficiențe de vedere. În concluzie, bijuteriile inteligente reprezintă o expresie semnificativă a tendințelor contemporane în modă și tehnologie, oferind oportunități noi de conectivitate IoT și flexibilitate în design.

Cuvinte cheie: *bijuteriile smart, inovație, designul podoabelor/bijuteriilor, podoabele contemporane, funcție.*

1. Introduction

In the context of rapid evolution in wearable technologies, smart jewelry marks a remarkable innovation at the intersection of fashion and technology. These accessories enhance the concept of traditional jewelry by integrating advanced functions such as health monitoring [1, 2], Bluetooth or Near Field Communication (NFC) connectivity, and Global Positioning System (GPS) location, all within a discreet and attractive design. Thus, in the 21st century, smart jewelry is increasingly sought after by modern users who seek a balance between technological functionality and personalized style. The evolution of these pieces derives from the desire for aesthetic and functional accessories that meet the need for portable technology. The integration of features such as health monitoring and smart notifications transforms these accessories into objects that combine aesthetics with practical benefits [3]. The design of smart jewelry requires a multidisciplinary approach, where engineering, art, ergonomics, and user psychology converge to redefine the concept of jewelry in the digital age.

Studies on smart jewelry highlight the importance of integrating health monitoring and connectivity functions into an aesthetic and sustainable design. Research emphasizes the challenges of balancing advanced technology with visual appeal, underscoring the need for recyclable materials and ergonomics for comfort and usability. Innovation in design consists of miniaturizing components and using flexible materials, enabling these accessories to provide advanced functionalities in a discreet manner, adaptable for both social occasions and daily use.

2. Materials and Methods

To carry out the research, a complex methodology was employed, based on multiple materials and scientific methods essential for ensuring a rigorous and well-founded analysis of the subject. The literature review involves examining previous studies, articles, and relevant academic works to understand the evolution and trends in the design of smart jewelry, exemplified by research such as "Innovation of Smart Jewelry for the Future," "The Future of Wearable Technologies" [4] and "Smart Jewelry: Balancing Functionality and Fashion." The case study investigates renowned jewelers or companies that have implemented innovative technologies in the design of smart jewelry, providing concrete examples of the application of the theoretical principles discussed and illustrating the impact of technology on aesthetics and functionality. Qualitative methods, such as interviews or surveys with users of smart jewelry, provide valuable insights into consumer perceptions and expectations, as well as the balance between aesthetics and functionality, with data being useful for assessing current preferences and trends. Comparative analysis, which compares different types of jewelry (smart, industrial, handcrafted), allows for the identification of distinctive characteristics and commonalities, as well as their environmental impact, supported by relevant tables and graphs. Observation and experimentation, through observing user interactions with smart jewelry and evaluating their performance under real-use conditions, provide empirical data on comfort, functionality, and aesthetics, aiding in adjusting the design to better meet consumer needs. Experimental research involves designing and creating prototypes of smart jewelry to test different combinations of materials and technologies, leading to innovative discoveries in design. Finally, the analysis of

technological trends, through studies on the evolution of emerging technologies (e.g., miniaturization of electronic components, use of flexible conductive materials), is essential for understanding the future direction of the industry. These scientific methods provide a solid foundation for research in the field of smart jewelry, helping to understand the complexity of the interaction between aesthetics and technology in contemporary design.

3. Results and Discussion

In the 21st century, wearable technology allows jewelry to expand its functions beyond traditional uses, including health monitoring, message notifications, movement tracking, event reminders, photography, and GPS localization. Smart jewelry products utilize technologies such as near-field communication, Bluetooth, and sensors for storing and transmitting information. These pieces of jewelry are classified into four main categories, as shown in Figure 1.
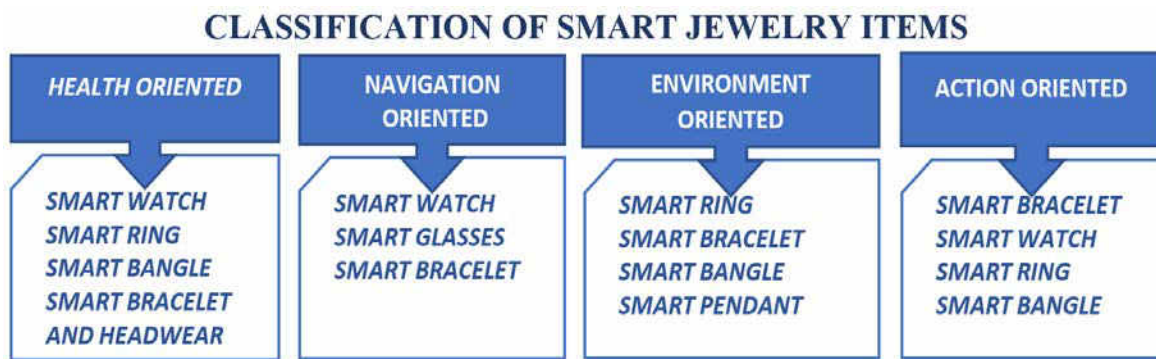
Figure 1. Categories of smart jewelry based on functional orientation.

Smart jewelry represents an emerging segment of the jewelry industry that incorporates technological functionalities such as health monitoring, connectivity, and security features [5] within an aesthetic design. These items meet the need to integrate technology in a discreet and elegant manner, making them appealing to users who desire portable devices without compromising their personal style [6]. These innovations open new opportunities for creativity and customization in jewelry design. However, technical and aesthetic challenges necessitate finding a balance between functionality and attractive design [7, p. 64-67] that meets the expectations of modern consumers. An analysis of commercial products shows that the most common forms are bracelets and haptic feedback [6, p. 4-5]. The aspects associated with the design of smart jewelry, highlighting both the advantages and disadvantages of these innovative accessories, are presented in Table 1.

Table 1

Opportunities and challenges of smart jewelry design

No.	Advantages	Disadvantages
1	***Extended functionality.*** Smart jewelry adds practical value to traditional jewelry through health monitoring functions [4, 8, 9] (Figures 2 and 3) security alerts (panic button bracelets) [5], and connectivity with mobile devices.	***Technology-limited design.*** The presence of electronic components (batteries, sensors, circuits) limits the aesthetic design options of jewelry compared to traditional pieces. Finding a balance between functionality and aesthetics can be a significant challenge.

2	**Customized aesthetics.** Smart jewelry, with a minimalist design and modularity, allows for personalization according to user preferences [10]. Companies like "Bellabeat" offer such options, facilitating the adaptation of the jewelry's appearance (Figure 4).	**Resistance and durability.** The integration of electronic components may make smart jewelry more fragile compared to traditional pieces, requiring additional protection from water or extreme temperatures.
3	**Convenience and integration into daily life.** Smart jewelry, such as smartwatches or rings with NFC functionalities for contactless payments, contributes to simplifying daily activities.	**Short battery life.** The small size of the batteries implies frequent charging, which reduces convenience.
4	**Promoting well-being.** Continuous monitoring of vital signs contributes to improved user health.	**Technological complexity (Figure 5).** Users may encounter difficulties using advanced functions without proper training.
5	**IoT technologies.** Smart jewelry allows connectivity to IoT networks for an extended user experience.	**High costs.** The integrated technology can significantly increase the price of these jewelry pieces.

Although smart jewelry offers extensive functionalities and opportunities for customization, challenges related to design, durability, and costs must be addressed to ensure their acceptance and success in the market.

Figure 2. „Oura" Ring 4 [11].

Figure 3. Fitbit Luxe Special Edition (Peony/Soft Gold)-JB Hi-Fi [12].

Figure 4. Leaf Urban, Bellabeat [13].

NFC Jewelry represents a type of smart jewelry that is part of the next generation of NFC wearable devices, focusing on quality design and advanced features. Each piece of jewelry, whether pendants, earrings, or rings, is equipped with an invisible NFC chip integrated into the sleek design, resembling classic jewelry. These pieces can interact with digital devices and exchange instructions and information, being compatible with both Android mobile phones and Apple iPhones. A notable example of interactive jewelry with NFC technology is the Momento collection from Galatea, which is patented and combines art with modern technology, allowing users to store personal memories in the form of voice messages, images, and texts Figure 6. To function, Momento jewelry requires a device with NFC support, such as an Android or iPhone. The creator of the "Smart Jewelry" line, the Momento collection, Davin Chi, describes this jewelry as "a digital locket for the 21st century," emphasizing its relevance in the contemporary context.

In 2015, the Hungarian company Liber 8 Technology released the smart bracelet Tago Arc, featuring a flexible e-paper display controlled via NFC. In 2024, users can change the image on the bracelet through one of the 9 applications such as Azure DevOps Solutions

Expert Master Program, Professional Certificate Program in Blockchain by IIT Kanpur, Big Data Hadoop and Spark Developer, PMI-ACP Certification, Search Engine Optimization (SEO) Course, Caltech-UI UX Bootcamp, Product Management Professional Program, Microsoft Certified Azure AI Engineer Associate: AI 102, Microsoft Certified Azure Fundamentals AZ-900, and upload their own designs, transforming from passive wearers into active creators. Tago Arc does not require charging, as it collects energy from the phone's NFC reader to update images Figure 7.

In 2016, a team of students created the StreetSmart app, which won first place at the Next Generation Mobility Challenge, a competition organized by Toyota and Net Impact aimed at motivating millennials to develop innovative solutions for mobility issues. The StreetSmart app was designed to assist individuals with visual impairments in spatial orientation by providing essential information about obstacles and changes in routes, such as malfunctioning escalators or bus schedule changes. StreetSmart integrates voice commands, GPS, crowdsourcing for traffic updates, and real-time notifications, thereby facilitating safe navigation and enhancing the user experience.

Considering that approximately 3.44% of the population has distance vision impairments, Toyota Figure 8 is concurrently developing Project BLAID [14], a wearable device designed for individuals with visual impairments [15]. This innovative device utilizes cameras and sensors to detect the surrounding environment, providing assistance through auditory feedback and vibrations, and integrating advanced features such as object recognition and obstacle detection. Thus, Project BLAID contributes to improving the safety and mobility of users with visual impairments, complementing and extending the solutions offered by the StreetSmart app to provide independence and an enhanced mobility experience.

Figure 5. Multifunctional Waterproof Smart Ring [16].

Figure 6. The Momento Collection, Smart Jewelry, Galatea [17].

Figure 7. Bracelet Tago Arc [18].

Figure 8. Toyota's guide collar for the blind and visually impaired [19].

In addition to these opportunities and challenges, the design of smart jewelry plays a crucial role in attracting consumers and balancing functionality with aesthetics.

Innovations and sustainability in jewelry design, smart technology, and contemporary design. Emerging technologies in smart jewelry design have diversified considerably in recent years. Among the main innovations influencing this field are the *miniaturization of electronic components*, the development of small-sized microchips, and flexible batteries [20], which have enabled the integration of technology into compact forms. These advancements make it possible for jewelry to maintain its elegance while also providing advanced functions, such as hiding a heart rate sensor or a panic button within a bracelet, without compromising aesthetics. Additionally, the *use of flexible conductive materials*, such as smart textiles or metallic nanoparticles, contributes to the creation of comfortable and functional pieces. This creative freedom allows designers to experiment with various shapes and textures. *Wireless connectivity and IoT (Internet of Things)* integration bring new opportunities for smart jewelry. Through Bluetooth or NFC connectivity, jewelry can interact with smartphones and other devices, expanding their functionalities within the user's digital ecosystem. At the same time, this integration necessitates a minimalist approach to ensure that the necessary antennas for connectivity are discreetly embedded in a subtle design.

The design of smart jewelry emphasizes both *functionality* and *traditional aesthetics*, as well as *comfort*. Designers must ensure that the aesthetics of the jewelry are not compromised by the integrated electronic components.

Current design trends focus on *customization* and *modularity*, allowing users to choose different aspects such as color, type of metal, or specific functionalities (e.g., heart rate sensor or GPS). This contributes to the increase of the subjective and emotional value of the jewelry. *Ergonomics* also represents a crucial principle, especially for jewelry worn for extended periods, such as rings, earrings, or bracelets. An ergonomic design must consider comfort, weight distribution, and minimizing irritation to ensure the experience is as pleasant as possible. For example, a ring with a small screen must be not only easy to read but also comfortable to wear.

The design of smart jewelry, industrial jewelry, and handmade pieces have distinct characteristics but also commonalities. Each type of jewelry has its own approaches regarding aesthetics, functionality, materials, and production processes.

The design of smart, industrial, and handmade jewelry presents both similarities and significant differences concerning aesthetics, functionality, and sustainability. All these categories of jewelry strive to be visually appealing, providing a sense of personal value and style to the wearer. Regardless of the type of jewelry - smart, industrial, or handmade - the main goal is to add an element of beauty and originality. Regarding the materials used, jewelry from all three categories may include precious materials such as gold, silver, and gemstones, as well as modern or advanced metals like titanium and high-quality plastics, especially in the case of smart and industrial jewelry. Customization is another important aspect, with each of these types of jewelry having the potential to be tailored to individual preferences. In handmade jewelry, customization is often more pronounced since each piece is crafted by hand and can be unique, while smart and industrial jewelry allows for the customization of functions, designs, and materials.

The differences between these three categories of jewelry are, however, evident. Smart jewelry is distinguished by the integration of modern technology, offering additional

functionalities such as health monitoring, smartphone notifications, or GPS protection. Its aesthetic is typically minimalist and technological, with materials that include lightweight metals, high-quality plastics, and sometimes electronic components like OLEDs or LEDs. In contrast, industrial jewelry is characterized by large-scale production, using mechanized processes such as casting or 3D printing [21, p. 35-37]. Their design is often standardized and less customizable, aimed at creating affordable products for the masses. Although quality may vary, these pieces are usually made from common metals and less durable alloys. Handmade jewelry, on the other hand, stands out for its uniqueness and creativity. Each piece is handcrafted using traditional techniques such as hammering or engraving, which gives them authenticity and artistic value. The materials used are often natural or recycled, with a focus on sustainability and exclusivity.

Smart jewelry can have a varied ecological footprint, depending on the life cycle of electronic components and the source of materials. Industrial jewelry tends to have a greater ecological impact due to mass production and the use of synthetic materials or lower-quality metals, although some companies adopt more sustainable practices. In contrast, handmade jewelry generally has a lower ecological impact, being produced in smaller quantities and often using recycled or renewable materials. Industrial jewelry focuses on mass production, with low costs and standardized design, but may sacrifice uniqueness. Handmade jewelry emphasizes *creativity*, *customization,* and *authenticity*, using natural materials and traditional techniques. Thus, each category of jewelry meets different needs and preferences, demonstrating the complexity and diversity of contemporary jewelry art. The similarities and differences between the design of smart, industrial, and handmade jewelry, as well as their environmental effects, are illustrated in Table 2.

Table 2

Sustainability and design of smart, industrial, and handmade jewelry

No.	Similarities	Differences	Comparing the impact on the environment
1	**Aesthetics and functionality.** All three categories of jewelry - smart, industrial, and handmade—aim to be aesthetically pleasing and provide the wearer with a sense of personal value and style. Each piece is designed to add beauty and originality.	**Smart jewelry design.** The design of smart jewelry is distinguished by the integration of modern technology, offering additional functionalities such as health monitoring, smartphone notifications, or GPS protection. Its aesthetic is minimalist, with a clean and functional design adapted to the integrated technology [22]. The materials used are advanced [23], including lightweight metals like titanium, aluminum, high-quality plastic, and smart materials like OLEDs or LEDs, which are not commonly found in traditional jewelry.	**Smart jewelry can have a varied environmental footprint,** depending on the source of materials and the lifecycle of electronic components. Generally, the focus is on *durability* and *modular design* to minimize waste.

2	**Valuable and diverse materials.** Jewelry in all three categories can be made from precious materials such as gold, silver, and gemstones, as well as contemporary metals and materials. Additionally, smart and industrial jewelry can also use advanced materials, such as titanium and high-quality plastic.	**Industrial jewelry design.** Industrial jewelry is *mass-produced* through mechanized processes, such as casting and 3D printing, allowing for quick and low-cost manufacturing [15 p. 154-155]. Its *design is standardized* and less customizable, aimed at mass consumption, which limits artistic innovation. Typically, these pieces are made from common metals and alloys with *variable quality* and may include synthetic or more affordable alternative materials.	**Industrial jewelry can have a higher environmental impact** due to mass production and the use of synthetic materials or lower-quality metals. However, some companies are also moving toward more sustainable processes.
3	**Customization.** All types of jewelry can be customized. Handmade jewelry offers greater customization due to the uniqueness of each piece, while smart and industrial jewelry allow for personalization through the selection of design, features, or materials.	**Handmade (artisanal) jewelry design.** Handmade, or artisanal, jewelry is distinguished by *creativity and uniqueness*, with each piece crafted by hand, meaning no two pieces are identical. Designers and artisans freely express their artistic vision, using *traditional techniques* such as hammering, engraving, and filigree, which *lend authenticity* and historical value. These pieces are far more *customizable*, often produced in *limited editions* or as unique items, reflecting the artisan's passion and frequently *using high-quality, natural or sustainable* materials, such as recycled metals and banana fiber.	**Handmade jewelry often has a lower environmental impact** because it is produced in smaller quantities and frequently uses *recycled or renewable materials*. Additionally, the production process is less polluting.

The design of smart jewelry focuses on the integration of modern technology and functionality, combined with a minimalist and discreet aesthetic. Industrial jewelry is characterized by standardized design, emphasizing mass production and low costs; however, this can lead to a sacrifice of uniqueness and customization. In contrast, handmade jewelry emphasizes creativity, uniqueness, and personalization, leveraging tradition and authenticity in the creative process. Each of these jewelry categories addresses different needs and tastes, but together they reflect the diversity and complexity of contemporary jewelry art.

Purchases and collaborations in the global smart jewelry market demonstrate the increasing importance of the fusion between technology and fashion, as well as the diversification of offerings to meet the varied demands of consumers. Major companies such as Apple, Fossil, and Samsung have invested in smart jewelry brands to expand their portfolio of wearable devices and include health monitoring, wellness, and connectivity features. These initiatives, along with partnerships with luxury designers and integration with fitness apps, reflect an ongoing trend to transform jewelry into functional devices, catering to both affordable and luxury market segments, contributing to the continuous expansion of this innovative sector.

4. Sustainability and energy efficiency in smart jewelry

In the current context, where sustainability and energy efficiency are becoming global priorities, smart jewelry aligns with these principles and successfully combines technology with environmental respect. Smart jewelry can be linked to sustainability and energy efficiency in several ways. First, the use of eco-friendly materials, such as recycled metals, natural fibers, or renewable sources like bamboo or banana fiber, reduces environmental impact and supports sustainability. Biodegradable or recyclable materials also contribute to a more environmentally friendly life cycle.

Another important trend in smart jewelry design is the integration of technologies that capture energy from natural sources, such as solar energy. Smart jewelry with small solar panels or those that utilize piezoelectricity (energy generated through movement) are examples of energy-efficient products, thereby reducing dependence on conventional batteries. Additionally, the durable and modular design of smart jewelry helps extend the product's lifespan since its technological components can easily be replaced or recycled. Instead of being discarded when the technology becomes outdated, these pieces can be updated by replacing parts, preventing electronic waste. Another key aspect for sustainability is low energy consumption. Energy-efficient sensors and chips help reduce the total energy consumption of the device.

Technologies like Bluetooth Low Energy (BLE) significantly reduce energy consumption, contributing to more sustainable use of the device. Furthermore, some smart jewelry pieces are designed to monitor and provide data about the surrounding environment, such as air quality or pollution levels. These products educate users about environmental impact and can encourage sustainable behaviors. Thus, smart jewelry not only offers a harmonious combination of aesthetics and technology but also contributes to a more sustainable and environmentally friendly industry.

5. Trends in smart jewelry design

Currently, the market share of smart jewelry is still small. Although various products have emerged, none have achieved significant success in the market; however, they have been effective in early consumer education [24]. The target group for smart jewelry is niche, making rapid penetration of the mass market challenging. Nevertheless, due to the increasing consumer interest and technological development, the barriers to popularizing smart jewelry will gradually decrease, and they will enter the lives of the general public. The development of smart jewelry not only expands the range of wearable devices [25] but also offers modernization opportunities for the traditional jewelry industry.

Many smart jewelry designers adopt a *minimalist style*, focusing on clean lines and simple shapes [26, p.87], which helps camouflage the technology and makes the jewelry appear as ordinary accessories. At the same time, the use of *natural materials and designs inspired* by elements of nature remains a strong trend, with the integration of wood, gemstones, and recycled metals adding a human and artistic dimension to a predominantly technological product. Additionally, some smart jewelry is designed to provide protection, such as necklaces or bracelets with integrated panic buttons that allow for the quick sending of alerts to trusted individuals, being discreet yet easily accessible in case of necessity.

Challenges in creating smart jewelry include *trade-offs between design and battery life*, considering the need to maintain a battery small enough not to affect aesthetics but strong enough to support smart functionalities. This involves optimizing every millimeter of

available space. Another aspect is the *durability of materials*, as the integration of electronic components can make jewelry more fragile; thus, the design must take into account resistance to shocks, water, and other usage conditions. Smart jewelry has the potential to revolutionize the traditional jewelry industry by adding a functional layer that meets modern user demands. They are perceived not only as fashion accessories but also as useful devices, thus expanding the target audience. In the future, technologies such as augmented reality and new user interfacing methods will continue to influence design, transforming jewelry into an integrated part of digital life.

Future prospects include *the use of new and sustainable materials*, such as biodegradable and recyclable electronic components, as a priority in smart jewelry design, thus contributing to reducing the carbon footprint and creating more environmentally friendly products. Additionally, *the development of modular smart jewelry* will allow users to upgrade devices without completely replacing them, promoting a more sustainable consumption model. Furthermore, as consumer accessibility and familiarity with these products increase, their *universality* will grow, and smart jewelry will become more popular and accessible, providing the traditional jewelry industry with an opportunity for modernization. Moreover, the *derivation of services* will transform smart jewelry from simple data-collection devices into part of an integrated service ecosystem, supported by technologies such as cloud computing and artificial intelligence, creating a close link between hardware and application services.

Advanced functionalities could incorporate health monitoring, including skin analysis and early detection of certain conditions, aiming to reduce reliance on smartphones by focusing on specific and useful functions to differentiate them from other wearable devices and make them indispensable. The integration of artificial intelligence could bring functionalities for analyzing collected data and personalized health suggestions. As technology miniaturizes, designers will have greater creative freedom, resulting in smart jewelry that is no longer limited by the size and shape of technological components, allowing for a greater diversity of styles and materials used.

6. Conclusions

Innovation in wearable technology in the digital era, especially in smart jewelry, is focused on meeting the needs of users, primarily women, who seek a combination of functionality, aesthetic design, ease of use, and affordability. The design of smart jewelry reflects a fascinating intersection between technology and aesthetics, with new innovations allowing the creation of jewelry that is not only attractive but also useful in everyday life. These products are designed to combine advanced technology with minimalist design, camouflaging technological components and ensuring that the jewelry remains stylish, accessible, and functional.

Moreover, the development of the smart jewelry industry has been driven by rapid technological evolution and market diversification, with an emphasis on sustainability and energy efficiency. Eco-friendly materials and modular design help reduce environmental impact, while innovations like the use of solar energy or piezoelectricity contribute to enhanced energy efficiency. Additionally, environmental monitoring technologies and low energy consumption through BLE demonstrate that these pieces are not just a fashion trend, but also a step toward more responsible and sustainable consumption.

Despite challenges related to the miniaturization of technology and its integration into durable and aesthetically pleasing designs, smart jewelry in the 21st century holds significant potential to become an integral part of everyday life. The traditional jewelry industry benefits from these innovations, while consumers gain access to customized products that blend utility with fashion. Thus, the future of smart jewelry looks promising, with increasing accessibility and popularity, and integration into AI-supported digital ecosystems will lead to a transformation of the industry.

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