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Review

The Potential of Visible Light Communications in Tourism and Hospitality: A Review of Applications and Perspectives

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Abstract

Tourism plays an important role in the global economy, contributing massively to the gross domestic product (GDP) and creating numerous jobs. The introduction of emerging technologies can accelerate the sector's growth through personalization, improved user experience and better operational efficiency. The present work investigates the impact of visible light communications (VLC) in the tourism and hospitality industry based on the analysis of the recent literature published in the last decade, with the scope of improving tourist experience, operational efficiency and sustainability. Additionally, this work aims to critically evaluate the advantages and disadvantages of implementing VLC technology in the tourism and hospitality industry. For these purposes, this study presents a narrative review of the recent academic literature. The findings indicate that VLC technology can be used in a wide range of tourism-related applications, including contactless hotel services, indoor positioning and navigation, secure communications, accessibility solutions for visually impaired individuals and energy-efficient lighting infrastructure. In addition, this review demonstrates VLC's potential to support the development of smart and sustainable tourism destinations through the integration of user-centered communication and illumination infrastructure. Finally, this work also identifies several challenges that affect large-scale deployment, including implementation costs, line-of-sight dependency and ongoing standardization issues.

Keywords: visible light communications; Li-Fi; tourism and hospitality industry; tourist experience; smart tourism; smart hospitality

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1. Introduction

Tourism represents one of the most important economic sectors, contributing significantly to the global gross domestic product (GDP) [1–3]. In 2025, the tourism and hospitality industry generated a record $11.6 trillion to the global economy, accounting for 9.8% of the global GDP and supporting over 366 million jobs globally [3]. This contribution exceeded pre-pandemic levels, with international visitor spending reaching $2.02 trillion, increasing

economic growth above the global average of 2.7% to 3.3% [4,5]. Looking toward the future, estimations indicate an increase to $16.5 trillion by 2035 (i.e., 11.5% of the global GDP) [2,3]. This prediction highlights the sector's resilience in the face of economic challenges. The role of tourism is even more important in specific countries that heavily rely on this business, generating vital returns for budget balances and a high employment rate. For example, in Mediterranean countries, such as Croatia, Greece or Portugal, the share of tourism in the economy reaches 18–25% [2,3]. In Croatia, the total economic contribution of tourism, including direct, indirect and induced effects, accounted for approximately 25% of the GDP in 2025, while the country recorded around 110.1 million tourist overnight stays, most of them concentrated in the Adriatic coastal regions [6]. Greece and Spain have seen a post-pandemic recovery, with over 10–15% more international arrivals compared to 2019, contributing to external tourism service surpluses [2,3]. Despite the benefits, these statistics highlight the vulnerability of these nations, where tourism generates major revenues but depends on seasonal and external factors.

The economic importance of tourism also highlights the need for continuous adaptation to new technological trends. From this perspective, the introduction of innovative solutions can bring significant benefits for the tourist experience and for operators [7–9]. In particular, new technologies, such as visible light communications (VLC) [10–12], have the potential to transform the tourism and hospitality industry by developing smart tourism destinations integrated within the smart city concept [13,14]. Developed on top of a pre-existing lighting network, VLC technology uses visible light from LEDs for simultaneous illumination and wireless high-speed communication [10–12], while also providing potential for high-precision distance measurement and relative positioning [15,16]. Thus, although, at this point, the implementation of VLC technology is still expensive due to its relatively early stage of development and limited large-scale production, the concept has strong potential to become a cost-efficient solution [17–19].

Similarly to conventional wireless communication technologies, such as Wi-Fi or Bluetooth, VLC also uses electromagnetic waves as a carrier for information. Nevertheless, differing from RF-based solutions that rely on the radio-frequency spectrum (such as the 2.4, 5, and 6 GHz bands), VLC uses the visible light component of the electromagnetic spectrum (i.e., 380–780 nm). Thus, the use of visible light represents one of the key distinguishing features of VLC. One important consequence is that VLC can be used for simultaneous illumination and data communication, with potential in environmental sensing, paving the way for a multi-purpose technology [20,21]. The use of visible light for communication provides a substantially larger unlicensed bandwidth. The approximately 400 THz-wide visible light spectrum provides a basis for very high data rates, which could reach above 100 Gb/s [22,23]. Additionally, the use of visible light makes VLC immune to radio-frequency interference. Moreover, in VLC, data are only available in "illuminated" places, which may enhance communication security by limiting signal propagation beyond the illuminated area. However, unlike RF-based technologies, VLC generally requires a line of sight between the transmitter and receiver. In turn, this affects the coverage and mobility, with its performance being influenced by obstacles, ambient lighting conditions and continuous illumination requirements.

In terms of utility, VLC is highly compatible with the tourism and hospitality sector, being well suited for various use cases in accommodation facilities (e.g., hotels and resorts), transportation (e.g., airports, airplanes, cars) and places of interest (e.g., museums, exposition areas). Thus, VLC could be used for automatic hotel check-in via smartphone screens [24–26]. In airports, VLC can provide connectivity, positioning and guiding services, whereas, inside airplanes, buses and cars, it can offer both ambient lighting and connectivity [27,28]. Moreover, VLC can significantly improve the visiting experience by

providing user-specific data distribution [29,30]. Overall, these solutions can reduce waiting times, improve the user experience and increase security, transforming tourist destinations into smart ecosystems [31]. Consequently, this has the potential to increase tourist loyalty and overall revenues, with a higher contribution to the GDP by improving operational efficiency and attracting technology-oriented visitors [12,32,33]. Additionally, numerous experimental investigations have shown that VLC has the potential to improve safety while traveling, not only for car drivers and passengers but also for pedestrians [34,35].

In this context, this article presents a narrative review focused on the potential of using VLC in the tourism and hospitality industry, based on an analysis of the literature published during the last ten years. The study addresses the limited number of academic investigations focused on how tourists could benefit from VLC technologies in their travel experiences. Moreover, this domain lacks comprehensive reviews published post-2021. There is a relevant and complex previous survey addressing optical wireless communications (OWC) technologies that was published in 2021 [13]. This work explores the potential of OWC in the tourism industry, addressing indoor and outdoor applications, and points out that these emerging technologies could have a major impact from three perspectives: travelers, tourist networks and tourist facilities. Nevertheless, the evolution of VLC technologies and the literature published after 2021 fully justify the need for an updated review. Therefore, this article provides an analysis of recent developments, emphasizes emerging applications and discusses the benefits and challenges associated with the large-scale adoption of VLC technologies in this sector. The main updates since 2021 that this article addresses are summarized in Table 1.

Table 1. Main research directions updated in the present review based on the literature published after 2021.

Research Direction	Main Post-2021 Developments Covered in This Review	Contribution of the Updated Review
Technical perspectives and potential applications	Recent experimental demonstrations, commercial Li-Fi systems, OCC developments, updated IEEE 802.15.7 standardization [36]	Updated overview of VLC technological maturity and deployment perspectives
Enhanced lighting and energy efficiency	Adaptive lighting, dimming techniques, flicker mitigation, human-centric lighting integration, lights-off VLC	Extended discussion of energy-efficient operation and user illumination
Security in tourism and hospitality	Balanced assessment of physical-layer security together with authentication, encryption, optical interception	Updated security analysis
Accessibility for vulnerable users	Additional studies on navigation and assistance systems for visually impaired users, including experimental validations	Expanded discussion of inclusive tourism services enabled by VLC
Smart tourism destinations	Recent literature on context-aware services, IoT integration, localization and personalized visitor services	Updated perspective on VLC integration into smart tourism destinations
Current challenges and future perspectives	Scalability, deployment cost, user acceptance, mobility, commercialization	Consolidated view of the remaining barriers to large-scale adoption

In this context, the main contributions of this work are (i) an updated narrative review of the literature published between 2015 and 2026 regarding the use of VLC in tourism and hospitality applications; (ii) the classification of the main application areas of VLC in the tourism and hospitality sector, including smart hotels, indoor navigation and positioning, enhanced user experience, improved energy efficiency, enhanced security, accessibility services and smart tourism destinations; (iii) a critical analysis of the benefits and limitations of VLC technologies from the perspectives of the tourist experience, operational efficiency, sustainability, security and accessibility; and (iv) a discussion of future research directions and adoption prospects for VLC technologies in tourism and hospitality environments.

The remainder of this paper is structured as follows. The following section describes the methodology used for this work. Section 3 presents a short discussion of VLC technology, aiming to provide the reader with the information required to understand the basic working principles of VLC and to realize its potential benefits in tourism applications. Section 4 reviews the relevant literature published during the last decade in the tourism domain and presents the main use cases of VLC in tourism-related applications. Section 5 presents and discusses some of the main findings, while the final section summarizes the conclusions of this work.

2. Research Methodology

The objective of this review is to highlight the impacts of VLC technology in the tourism and hospitality industry and to emphasize the benefits that the integration of VLC could provide for this industry. Additionally, the challenges and the disadvantages of implementing VLC in the tourism and hospitality sector are also brought to light based on the findings extracted from the current VLC literature. In order to remain relevant and avoid overlapping with previous works [13], this review focuses on the scientific literature from the last ten years. Thus, this narrative review examines studies published between 2015 and 2026. Consequently, as this work is a narrative review, the literature search was intended to provide a broad and representative overview of recent developments. Therefore, the review methodology did not follow that of a systematic review, meaning that no predefined PRISMA protocol, duplicate removal procedure or quantitative study selection process was applied. Instead, the considered publications were selected based on their relevance to the topic, scientific quality, recency and their contribution to the field of VLC applications in tourism and hospitality. Publications that focused on validated tourism applications were prioritized, but, since this is an emerging research topic, studies describing enabling VLC technologies with potential relevance for tourism were also included.

The studies were identified through searches in IEEE Xplore and Google Scholar, complemented by relevant articles published in peer-reviewed scientific journals, including journals published by MDPI, conference papers, recent statistics and websites. Searches were conducted in academic databases using keywords such as “visible light communications” and “Li-Fi”, combined with application-oriented terms including “tourism”, “hospitality”, “hotels”, “museums”, “airports”, “smart cities” and “indoor positioning”. Additionally, in order to provide a broad perspective, this review also takes into account relevant studies that present concepts that could have an impact on the tourism industry, even if the authors did not mention it explicitly. The thematic analysis found recurring themes related to the implementation of VLC and LED-based systems for simultaneous illumination and communication, accessibility support for people with eyesight problems, indoor information delivery and intelligent transportation applications. The methodology adopted in this review is graphically illustrated in Figure 1.

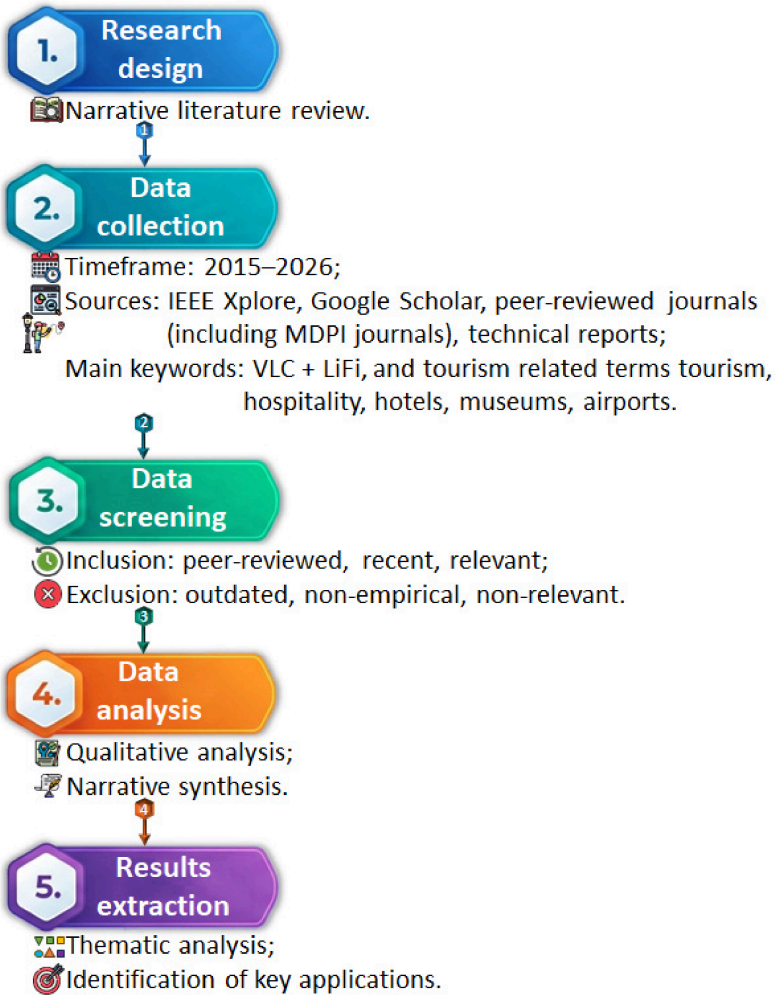


Figure 1. Flowchart of the literature selection process and methodological approach.

3. Visible Light Communications: An Overview of Principles, Features and Relevance for Tourism Applications

Before debating the use of VLC in tourism applications, this section aims to introduce VLC technology and its benefits. VLC is an emerging technology that uses the visible light spectrum for simultaneous illumination and data transfer [10–12]. The technology has very high potential as it addresses several important issues related to wireless communications. Compared to radio-frequency (RF)-based technologies, where there is a limited bandwidth (i.e., 300 GHz), the visible light spectrum is more than 1000 times greater. This enables significantly higher data rates and a larger number of connected devices and reduces spectrum congestion [23].

Compared with conventional RF-based communication technologies, VLC differs in both its operating spectrum and transmission principle. RF-based technologies transmit data by modulating radio waves generated specifically for wireless communication. This generates a certain level of energy consumption and, in turn, ensures that, due to the specific characteristics of RF waves, the signal can propagate through walls and over relatively large areas. By comparison, VLC relies on the modulation of the LED light intensity, enabling simultaneous illumination and wireless communication. As a result, no additional energy is required to generate a dedicated communication carrier (i.e., the data are transported by the light used for lighting purposes), and the technology is immune to RF interference. From a different perspective, the intrinsic properties of light prevent it from passing through opaque objects or walls, maintaining the communication in a restricted

area. Thus, differing from RF-based systems that generally provide wider coverage and better support for user mobility, VLC solutions enable data transfer within a confined area. In certain cases, this is a positive aspect as it limits interference between neighboring links and facilitates the deployment of "small cells", significantly improving the communication performance [22,23]. Additionally, this improves physical security for data. However, in order to enable connectivity in user mobility conditions and to handle multiple users, specific technical solutions are required (e.g., handover mechanisms between adjacent VLC access points, multiple-access techniques, adaptive resource allocation).

Another important aspect is the fact that VLC technology is developed on a widely available lighting network based on LEDs. In this regard, information is modulated on the optical carrier, meaning that, unlike any other communication technology, data transmission does not require additional energy consumption to generate a data carrier (i.e., in addition to the one already used for illumination). Therefore, the technology penetration potential is very high, as VLC may enable the transformation of any LED light source into a data transmission device. Within this context, although the cost of VLC implementation is high at present, the preexisting lighting network offers a basis for improved cost-efficiency. In addition to simultaneous illumination and data communication, VLC technology can also be used for distance measurement and accurate localization [12,16], providing extra benefits and further improving cost-efficiency.

A very important aspect that supports the development of VLC technology is its safety for human exposure. Unlike RF-based communications, VLC relies on visible light for data transmission and is generally considered harmless regarding human exposure under normal operating conditions. Meanwhile, the potential long-term biological effects of RF electromagnetic fields continue to be investigated and have been discussed in the scientific literature [37–39]. Therefore, in tourism applications, this feature could become attractive in environments where tourists seek comfort and relaxation and where they prefer not to be exposed to RF. Such a feature makes VLC especially suitable for hotels, wellness centers, hospitals, airplanes and other tourism-related environments where tourists wish to enjoy an RF-free environment.

Based on optical carrier modulation, at the VLC transmitter side, LED light sources are switched on and off at very high frequencies (e.g., from hundreds of kilohertz to hundreds of megahertz or even gigahertz). As shown in Figure 2, this requires a relatively simple architecture, mainly consisting of a data processing unit (e.g., a microprocessor), which generates the data to be transmitted, and a digital switching circuit that controls the LEDs. At the receiver side, a photosensitive element, usually a PIN photodiode, is used to convert the incident light into a proportional electrical current. Next, the photocurrent is processed through a transimpedance circuit, which converts it into a voltage signal that is then filtered, amplified and digitized until the original signal is recovered. Finally, the reconstructed signal is provided to a data processing unit, which extracts the transmitted data and delivers them to the user device. In practical Li-Fi solutions, the uplink is usually created using infrared optical communication [40], whereas, in other cases, the uplink is formed through conventional RF technologies, depending on the application requirements and system architecture.

Besides the photodiode-based VLC architecture, another important VLC implementation is represented by the optical camera communication (OCC) solution [36,41]. In OCC systems, the optical signals transmitted by LED sources are received using a camera sensor, similar to the ones commonly integrated into smartphones. This approach eliminates the need for dedicated optical receivers and enables a wide range of location-based services, such as information delivery, indoor positioning and navigation. Due to the limited frame rates of conventional smartphone cameras, OCC generally provides lower data rates than

photodiode-based VLC systems, but its compatibility with existing users' smartphones makes it particularly attractive. Moreover, users can access such services by installing a dedicated mobile application, without requiring any additional hardware. The high potential impact of this specific use case is also confirmed by recent OCC standardization efforts [36]. Moreover, OCC has been included in the IEEE 802.15.7 standard for optical communications using visible light.

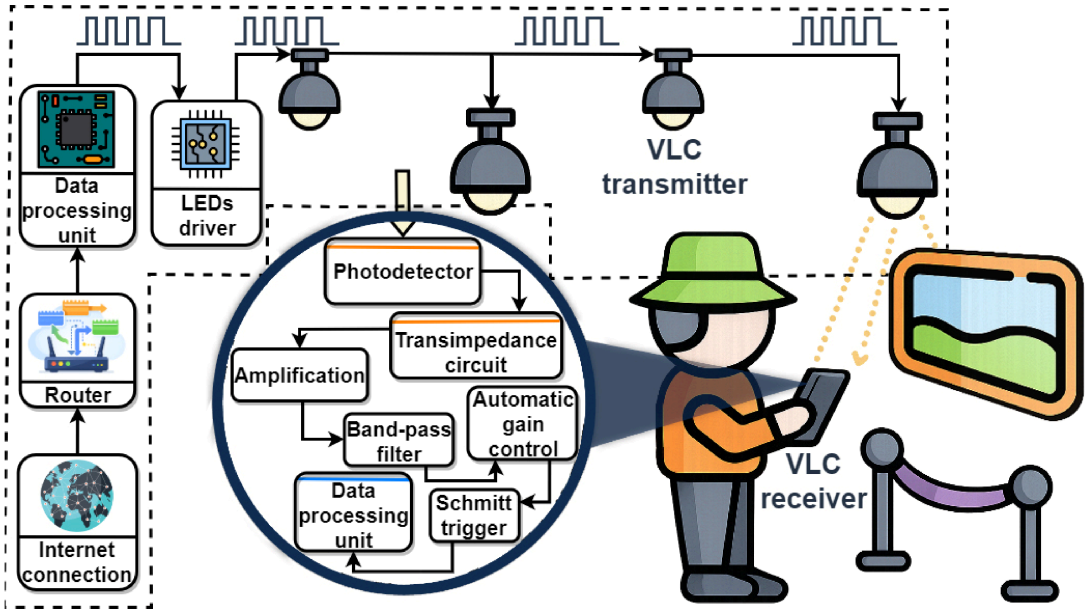


Figure 2. Example of VLC architecture.

The structure of a VLC system reveals one of its most important features. Since connectivity requires that the light generated by the transmitter reaches the surface of the receiver, VLC is inherently a line of sight (LoS)-dependent technology. However, this characteristic can affect connectivity when the LoS between the transmitter and receiver is obstructed, while also limiting mobility and coverage. In VLC, data are available only in areas exposed to light, either directly or indirectly. Although LoS dependency is a disadvantage from certain perspectives, this aspect also provides an important security advantage [31]. Since VLC signals are generally restrained within limited physical spaces, such as rooms or indoor environments, VLC systems may provide an additional layer of physical security against eavesdropping and unauthorized external access. However, this physical-layer advantage does not guarantee the security of information and such a system cannot replace conventional cybersecurity mechanisms. Similarly to wireless fidelity (Wi-Fi) networks, VLC systems continue to rely on authentication, encryption, secure key management and endpoint protection to ensure end-to-end communication security. For comparison, the signal of a Wi-Fi access point (AP) can be detected from distances of up to 35 m in indoor conditions and up to 250 m in outdoor conditions, which renders them more vulnerable to unauthorized access and interception. Under these conditions, VLC can provide additional physical security by limiting signal propagation beyond the intended coverage area. This represents another important advantage of VLC.

Finally, yet importantly, VLC has a unique ability to provide location-aware or location-dependent personalized content. Unlike RF-based wireless technologies, where the coverage area of an AP is relatively wide, VLC benefits from the small-cell concept [23]. Thus, a person located within the coverage area of a VLC AP (e.g., a lighting fixture) can receive dedicated content relevant to their precise location. This transforms connectivity into a more personalized and enhanced user experience.

Research focusing on VLC development was initially oriented toward improving specific performance. From this perspective, two main areas were considered. First, important research efforts were dedicated to improving the data rate. As a result, impressive data rates have been experimentally confirmed, reaching up to few tens of gigabits per second [42–45], whereas commercial solutions that provide strong performance are also available [46]. Secondly, due to the intrinsic characteristics of light, important research efforts were directed to improving VLC's resilience to optical interference. This led to VLC systems that are able to work under exposure to intense optical interference [34,47] and that can cover ranges extending up to almost 200 m [34]. Another important aspect was the development of solutions that enable the use of the VLC technology for ranging and positioning applications [48,49]. Thus, as technological issues have been partially addressed, the next step is to investigate its use in specific application domains. In this context, due to the increasing demand for high-speed connectivity, precise indoor localization and enhanced user experiences, the tourism and hospitality sector emerges as a particularly suitable field for the deployment of VLC technologies.

Another important aspect that deserves discussion is the common perception that VLC requires the associated lighting to remain continuously active and that it could introduce flicker. However, from the early stages, the VLC technology has been developed by focusing on ensuring compatibility with user illumination requirements. Thus, the use of lighting infrastructure for data transmission should not compromise the primary lighting function [50,51]. Specifically, on the one hand, this means that no flicker should be generated by the lighting transmission function. In practice, flickering is prevented by using high modulation frequencies (i.e., typically above 200 kHz) and coding techniques in which the average optical intensity is not dependent on the transmitted data. These coding techniques, referred to as run-length limited (RLL) codes, ensure a balanced distribution of logical "1" and "0" symbols, resulting in constant light output and preventing perceptible flicker for human users. On the other hand, users should be able to adjust the light intensity in accordance with their preferences or needs. Focusing on this second aspect, certain modulation techniques that enable simultaneous optical wireless communications and simultaneous light intensity control have been designed. For example, in variable pulse position modulation (VPPM), the bit period is kept constant, whereas the "light-on" percentage is adjusted in order to increase or decrease the light intensity. Following this approach, the "lights-off visible light communications" concept has emerged [52]. This concept enables the VLC link to remain active, while decreasing the light intensity down to limits at which the human eye perceives them as being completely off. In practice, light is perceived as completely off when the on percentage decreases below 0.007% [53], with light being barely perceived when the on percentage decreases below 1% [54]. As a result, VLC systems can work in dark conditions without affecting their connectivity or coverage.

In conclusion, the features of VLC highlight its strong potential to become an important, transformational technology in the tourism and hospitality industry. By unifying illumination, wireless communication and localization, VLC enables high-speed, secure, energy-efficient and location-aware services. In turn, these services can significantly improve the tourist experience in places such as hotels, museums or airports, transforming them into smart tourism destinations.

4. Visible Light Communications in the Tourism and Hospitality Industry: Literature Review

4.1. Technical Perspectives and Potential Applications

Despite the recent academic attention paid to the use of VLC technologies in the tourism and hospitality industry, additional research is needed to implement smart solu-

tions for the multiple uses of VLC technologies, as well as to stimulate research efforts in this direction. Although more researchers are looking into the impacts of VLC technologies on the tourism and hospitality domain, the motivations for adopting these smart technologies remain insufficiently explored. Recent studies from 2015 to 2026 show that the use of VLC could have an important role in connecting the various experiences of tourists with shared advantages in their own lives.

The development of smart tourism is driven by the advancement of new-generation information technologies such as 5G/6G, cloud computing, big data and artificial intelligence (AI) and is leading to significant transformative shifts in this sector [55,56]. This evolution is changing traditional methods of marketing and provides the basis for a new chapter in the travel domain. Using digital solutions is very important in providing customers with the best service and ensuring their safety in the tourism and hospitality industry [57]. The authors of [58] consider that the positive experiences and happiness of hotel visitors are correlated with the implementation of smart technologies that improve their overall travel experiences. These advancements consist of automatic check-in and check-out systems, smart concierge services, improved in-room features and the use of robots for room service. The authors of this study consider that the integration of such innovative changes in the hospitality domain leads to improved guest experiences and stays that are more enjoyable.

In this regard, the authors of [59] explore a tourist interpretation system that uses VLC and consider that the introduction of optical technologies could provide new energy in the development of tourism and facilitate the transition toward smart tourism. The proposed concept considers that LED light sources can provide services like text, audio guidance and smart navigation for users. The authors also consider that these features enhance travel experiences and meet the specific needs of tourists. The developed intelligent light control tour guide system renders the tour smarter and more interactive, clearly showing the features and the value of tourist attractions and helping in teaching and explaining aspects to visitors. The high potential of VLC, and particularly of light fidelity (Li-Fi), is also emphasized in [60,61]. Such works highlight Li-Fi's ability to provide a new way to transmit data. Li-Fi improves current wireless networks and supports the systems used in future smart cities and Internet of Things (IoT) platforms. Li-Fi represents an advanced implementation of VLC technology, designed to provide functionalities similar to those of Wi-Fi. In this regard, Li-Fi can deliver wireless internet connectivity while supporting multiple users, user mobility and complex utilization scenarios [41].

The use of VLC technologies to provide information to tourists in multiple foreign languages is discussed in [62]. According to the authors, the inclusion of information written in foreign languages compromises convenience for local tourists because it reduces the available display area. A solution to this problem could be found in the use of digital signs to share information. With this approach, local tourists can obtain information through standard text, whereas foreign tourists can use the image sensors within their smartphones to receive information in their own language, transmitted via VLC. To achieve this goal, the authors provide a demonstrational system that includes a display panel as a transmitter and an image sensor as a receiver, proving the viability of the concept.

Because tourism concerns not only the destination but also the journey, VLC-enabled reading lights in aircraft can transmit personalized entertainment without affecting radio systems. Aviation applications enable secure onboard entertainment, without interference with critical radio systems, enhancing comfort and the overall travel experience [13,63–67]. Within this perspective, it should be noted that the integration of VLC technology for in-flight applications is not limited to the theoretical level, as commercial companies are already able to deliver such solutions [66]. In the same travel context, Li-Fi solutions also have significant potential to enhance the transportation experience in metro and train sta-

tions, as well as in airports [68–70]. In these environments, optical wireless communication technologies can provide not only high-speed connectivity but also dedicated navigation and guidance services. Such enhanced functions could help tourists to navigate unfamiliar locations more efficiently and confidently, further enhancing their journeys.

4.2. Use of VLC for Enhanced Lighting Experience and Energy Efficiency

VLC could have an important positive impact on the tourism ecosystem due to the positive impacts of technology on energy efficiency [71,72]. As VLC is based on LED lighting infrastructure, this means that no extra energy is used for providing wireless connectivity within a space. From this perspective, based on the average energy consumption of a Wi-Fi router, and on the results reported in [19], 7–10 kWh per month can be saved for each piece of equipment, lowering the power consumption of the tourism facility. In addition, energy efficiency is further enhanced by the multifunctional nature of VLC technology, enabling its use for other applications. For example, the authors of [73] show that VLC could be also used for space monitoring and intruder detection.

In terms of VLC development, some research has been carried out to increase the data rate and enhance the lighting quality. In this context, it is important to ensure that the illumination is adequate and safe for users while also being able to support the communication function. From a lighting utility perspective, brightness and chromaticity are two main characteristics that indicate the appropriateness of LED light [74]. The authors of [75] emphasize, in their paper, that VLC applications must consider its role in providing illumination as well as its main communication function, providing an innovative means of wireless communication indoors. In this regard, dimming control is one of the most important features for managing light in VLC systems. As a response to these challenges, the authors of [76] focused on developing indoor VLC systems that are able to provide simultaneous data transmission and adjustable illumination. The proposed prototype enables light intensity control between 1% and 99% with a 1% resolution. The system uses VPPM and is able to provide a BER lower than 10^{-6} for a 3 m range around each luminaire. Following this path, in [19], the authors focused their attention on using VLC in order to provide a more energy-saving option for today's public areas. Thus, in this work, the authors provide experimental results for a VLC system that is able to automatically adjust its light intensity in accordance to users' preferences and the natural illumination within the workspace area. The proposed concept is able to transmit wireless data and to dynamically adjust its duty cycle in order to maintain a constant light intensity at the workspace level. Based on these features, the system is able to ensure energy savings that range between 23% and 69%, depending on occupancy and the natural illumination conditions. Although the proposed solution was not tested in a tourist facility but in a regular office, these results indicate the potential to improve profitability in the tourism and hospitality sector, where lighting systems are extensively deployed and occupancy levels vary constantly throughout the day. In accordance, by adapting illumination to real-time user presences and demands, substantial energy savings can be achieved without compromising user comfort or quality of service (QoS).

Moving forward, the authors of [77] propose the merging of VLC and human-centric lighting (HCL). This new concept assumes that VLC lighting sources should not only transmit data and adapt their lighting intensities but should also enable color adjustment in accordance with users' preferences and activities and/or the time of day. The paper presents use cases and emphasizes the high potential of this new concept in tourism and related fields. Additionally, this work includes a detailed technical analysis and emphasizes the high compatibility between VLC and HCL and the fact that new benefits can be

explored. Although this works remains at a theoretical level, it provides a strong analysis that indicates strong potential in tourism facilities.

To provide an argument for their work on VLC, the authors of [78] show that there are numerous economic and energy efficiency benefits of using VLC technology. The economic benefits of VLC use include operational cost reductions achieved by the integration of the technology into existing LED lighting. This improved energy efficiency comes from the reduced LED energy consumption, which, in turn, contributes to sustainability and important savings in hotel expenses. The cost efficiency of VLC also comes from reduced connectivity costs. Specifically, by repurposing LED lights for data, the reliance on dedicated Wi-Fi and cabling is partially eliminated. As well as consuming less energy than traditional bulbs, VLC LEDs come with a longer lifespan, contributing to lower replacement and maintenance costs. Nevertheless, it should be emphasized that these economic benefits depend on the specific lighting infrastructure, occupancy profile, maintenance strategy and specific deployment scenario.

From the same economic perspective, the authors of [79] show that the economic differences between VLC and Wi-Fi in tourism come from VLC's dual-use infrastructure. In VLC, this unique concept reduces long-term costs, unlike Wi-Fi, where recurring investments in routers and upgrades are required. The authors also emphasize that, even if VLC has higher initial costs, it offers superior energy savings (i.e., LEDs are more energy efficient than Wi-Fi routers) and enables the reuse of LEDs. In contrast, Wi-Fi involves ongoing maintenance costs and upgrades to Wi-Fi 7, which is important for high-data-rate connections and IoT services in hotels. Therefore, the VLC market strong growth potential as it provides premium services without additional cables and/or complex infrastructure. Thus, when deployed in accommodation facilities, VLC can provide competitive advantages through improved sustainability and operational efficiency, potentially reducing medium-term operational costs. Table 2 summarizes the main economic differences between Wi-Fi and VLC technologies.

Table 2. Comparison of the economic characteristics of Wi-Fi and VLC technologies.

Economic Aspect	Wi-Fi	VLC
Initial deployment cost	Low (mature technology)	Currently high but expected to decrease with large-scale commercialization
Infrastructure	Dedicated APs and network cabling	Reuse of LED lighting infrastructure
Additional hardware	Dedicated APs, routers and switches	VLC controllers and compatible receivers
Operational cost	Communication infrastructure only, represented by AP maintenance and upgrades	Potentially lower due to infrastructure sharing, reduced energy consumption and LED reuse
Scalability potential and scalability cost	High scalability potential, with well-established large-scale deployments; low cost scalability	Scalability currently limited by deployment complexity and evolving standardization; higher deployment cost for large-scale installations
Maintenance	Network equipment	Integrated lighting and communication infrastructure
Long-term operational cost	Periodic AP replacement and technology upgrades	Potentially lower due to dual-use infrastructure and lower energy consumption
Typical applications	Connectivity	Connectivity, smart lighting, positioning, integrated lighting–communication–sensing, smart buildings, tourism

Note: The comparison is qualitative and summarizes the main characteristics in the literature. Actual costs depend on the specific application scenario.

4.3. Use of VLC for Improved Security in Tourism and Hospitality

VLC technology could offer the possibility to improve security in hotels and tourist destinations through its physical nature, which restricts optical signals within the premises. This intrinsic characteristic of VLC can significantly reduce the probability of the unauthorized external interception of transmitted data by restricting the optical signal within the illuminated area [31]. Thus, unlike Wi-Fi, where RF signals can be intercepted from a distance that is usually significantly larger compared to the serviced area, VLC uses visible light that does not penetrate walls. This feature can reduce the risks of unauthorized signal interception and certain physical-layer attacks in sensitive environments, such as reception areas or hotel rooms, protecting sensitive information (e.g., tourist profiles) from theft via public wireless networks. Nevertheless, as with any wireless communication technology, VLC continues to use conventional cybersecurity mechanisms, including user authentication, encryption, secure key management and endpoint protection. Moreover, in hotels and accommodation facilities, VLC enables automatic check-in by scanning LED lights at the reception with a phone's camera, generating secure digital keys and reducing waiting times [13,26,79,80]. Moreover, Li-Fi systems provide broadband connectivity in rooms without the need for additional cables and without exposing tourists to RF interference [13,81].

Despite the high potential for improved security, certain authors [13,81] have debated the specific security risks of VLC. For example, crowded tourist areas such as hotel lobbies, airports or museums could present specific security threats. These risks are related to the optical nature of the technology and are amplified in high-density user conditions. Risks can be generated by vulnerabilities to physical interference and targeted attacks. On the other hand, these risks can be mitigated with the help of hybrid network designs and adapted communication protocols [82,83]. In crowded environments, the main risk is optical eavesdropping, where a strategically positioned attacker can capture VLC signals. However, it should be mentioned that, in this case, eavesdropping would be limited to the LoS (i.e., 1–5 m). In addition, VLC could be vulnerable to targeted attacks achieved by intentionally blocking light (i.e., physical jamming with opaque objects), causing localized denial-of-service (DoS).

Another theoretical risk is light interference, where external sources (e.g., phone flashes, sunlight through windows) could induce bit errors. Nevertheless, intensive research efforts, mostly focusing on vehicular VLC applications, have led to very noise-resilient systems that are able to cope with extreme optical noise interference [34,35,47]. Another vulnerability of VLC occurs in dense areas, when a high number of users is located within the coverage of the same LED luminaire. These conditions can generate multi-user collisions that lead to increased latencies and affect data rates [84,85]. These risks can be mitigated through directional beamforming [86–89] (i.e., light focused on the user), advanced encryption and hybrid RF handover for non-LoS [82–85,90].

The authors of [79] report results from an expert panel, highlighting the advantages and challenges of VLC use in the tourism industry. The authors examined three scenarios: the traveler's perspective, the tourism facility perspective (i.e., hotels, restaurants, museums, etc.) and the broader tourism destination perspective (i.e., the city or region where the tourist is received). In hotels, VLC provides broadband access through LED lights, reducing cabling and improving personalized services. Secure check-in and access to guest rooms by scanning LED lights with a phone's camera through VLC eliminate the need for physical keys or passwords, which are vulnerable to phishing. This work also points out that VLC improves security by eliminating the possibility of signal interception beyond the LoS. Thus, in accommodation facilities, VLC becomes ideal for financial transactions or guest personal data, providing an additional layer of physical security compared

with conventional RF-based wireless communication solutions. Moreover, in this context, studies indicate that VLC can improve security in enclosed spaces by reducing the risk of external attacks, such as eavesdropping or man-in-the-middle attacks, due to its capacity to maintain the data within a restricted area. Moreover, VLC can be integrated with IoT systems to enable EMI-free applications, being suitable for applications such as camera surveillance and luggage tracking [79,81].

The authors of [13] also highlight the importance of VLC for hotel security due to the signal being physically limited to the room space. This makes VLC suitable for sensitive areas, such as hotel receptions, guest rooms and access control systems, reducing the risks of hacking and unauthorized access. This extra feature complements and even improves on traditional Wi-Fi encryption systems, such as WPA3. It eliminates common RF attack methods in hotels, where guest Wi-Fi networks are vulnerable to mass interception. VLC creates naturally isolated zones for each room or lobby, which cannot be intercepted from nearby rooms or outside the building. Although Wi-Fi uses AES-256 (WPA3), attacks such as Key Reinstallation Attacks (KRACK) or deauthentication are still possible. Meanwhile, VLC substantially limits interception outside the illuminated area without direct access [79,82,90]. VLC also provides digital keys transmitted through LED lights at reception, scanned by smartphones for room access, with two-way authentication and automatic expiration [24–26]. Indoor positioning through OCC, with accuracy below one meter, can detect intruders in real time and connect with alarm systems, improving internal security [73]. Combined with RFID or video analytics, VLC can be used to monitor room occupancy and detect unusual situations (for example, abandoned luggage) without exposing the central network. In addition, by processing data locally, VLC reduces the dependence on vulnerable cloud systems.

4.4. Use of VLC to Improve Tourism Accessibility for Vulnerable Users

In their studies, the authors of [91,92] showed that VLC technology has the potential to also meet the needs of vulnerable users, such as tourists with visual impairments. These studies indicate that the integration of VLC is able to provide a significant advancement in improving their quality of life and travel independence. These works provide experimental evaluations of portable VLC devices that enable visually impaired persons to travel in unfamiliar places. The portable device receives modulated signals from light sources. These messages contain the current location, information regarding points of interest and indications that should help the person to travel from one place to another. The portable device extracts the data from the optical signals and transforms them into voice messages or into haptic information that is accessible for visually impaired users. Additionally, the portable device scans the area around the user in order to detect potential obstacles. Again, this information is provided to the user by haptic means. Notably, this concept has moved from theory to practice, reaching Technology Readiness Level (TRL) 6. In terms of performance, the proposed prototype was able to provide almost error-free communications, with a bit error ratio (BER) of 10^{-7}. The experimental evaluation shows that people using this equipment are able to travel 22% faster and that they are able to locate interest points without help from others. Therefore, although this system has not been specifically designed for tourism applications, it could help by improving users' independence and encouraging them to travel more freely, contributing to their well-being and to the tourism sector.

Academic researchers over the last ten years also highlight the use of VLC in aviation for in-flight data transmission via reading lights and in museums for interactive information via augmented reality (AR). In [93], the authors propose the integration of VLC into traffic lights for visually impaired tourist guidance in smart cities. The purpose of the concept is

to have user information points distributed at various points in the city and, secondly, to ensure universal accessibility for all.

The authors of [94] also emphasize that VLC could have a role in improving accessibility for severely visually impaired individuals. This work demonstrates the high potential of VLC and its even greater potential when combined with AI. The study shows that, based on these innovations, blind individuals could achieve a relatively high level of independence, which may encourage them to become active tourists. In turn, this could significantly improve their quality of life and contribute to the development of the tourism industry.

In smart cities, street lights with LEDs could emit geo-referenced IDs synchronized with digital maps, allowing seamless indoor–outdoor handover (for example, from a museum to the street). Predictive AI algorithms adjust routes to avoid crowds or roadworks and can be integrated with applications such as Step Hear or Visit City (with the signal being limited to the LoS) [13,19,79,82].

VLC can be integrated with tactile carpets in tourist museums by combining physical haptic guidance (tactile reliefs on the carpet) with discrete optical signals emitted by overhead LED lighting, creating a multimodal navigation system for visitors, especially for visually impaired people. This combination transforms exhibition routes into highly accessible experiences, where the carpets provide basic tactile orientation and VLC adds real-time contextual audio precision, increasing inclusion in tourist spaces. Tactile carpets (markings according to SR EN 17210 [95]) are placed on the floor as raised strips or arrows, guiding steps toward key exhibits. Above them, ceiling LEDs or directional spotlights emit modulated VLC signals (e.g., low-frequency on–off keying (OOK)-modulated signals), detectable by a smartphone or smart cane through a photodiode/camera at an LoS height. When detected, the system triggers audio descriptions synchronized with the tactile position, avoiding confusion in crowded rooms. Handover is automatic: the carpet vibrates at intersections, while VLC confirms the exact direction [13,94].

4.5. Use of VLC for Smart Tourism Destinations

VLC could transform tourism in smart cities through its integration into the existing lighting and signaling systems, such as traffic lights, informative panels or public lighting with LEDs, and through the creation of hybrid optical networks capable of providing the necessary infrastructure for new, personalized and sustainable applications [13,14]. Such integration transforms cities into interconnected informational nodes that can help tourists to obtain real-time information while reducing RF spectrum congestion in dense urban environments. Moreover, VLC forms, within the architecture of the smart city, a complementary optical layer connected to IoT and 5G networks through hybrid gateways. Thus, the public lighting system can provide support for guidance by emitting the signals necessary for vehicles and pedestrians, while informative panels with LEDs in squares or stations could provide geolocated content, such as information about a historical monument that has been captured with a phone. In tourist destinations such as Las Palmas (Spain), a VLC traffic light project experimented with guiding blind tourists and large groups of visitors toward attraction points integrated into tourist area network (TAN) mobile applications [93].

VLC personalizes content for tourists by dynamically modulating LED light signals that transmit geolocated data adapted to the user profile detected through smartphones in the LoS, using the OOC branch of VLC. This approach creates hypercontextual experiences in real time, increasing engagement through improved contextual interaction in smart destinations [13] without requiring additional complex applications. Personalization involves the automatic identification of the tourist by scanning LED lights with a phone camera, which decodes a unique ID linked to the profile (e.g., language, preferences in the

travel app or previously scanned quick response (QR) data). The central server matches the profile with relevant content: cultural history in the user's native language, restaurant promotions based on diet or personalized routes that avoid crowds [62,96].

The process of integrating VLC technology involves (1) upgrading public LED lighting sources with modulation drivers; (2) OCC sensors and dedicated software applications in phones for decoding purposes; and (3) a central cloud for data aggregation (tourist traffic, preferences, etc.) [13,79,81]. Regarding the challenges of integrating VLC into smart cities, the authors mentioned above highlight the limitations caused by the LoS condition outdoors (reduced through optical repeaters) and IEEE 802.15.7 standardization [97–100]. In street lighting, these challenges come from exposure to harsh environmental conditions and strict continuous operation requirements, which make it more difficult to implement complex LED modulation schemes for data transmission without affecting the uniform illumination needed for tourist safety. Regarding ambient interference, direct sunlight or light pollution (e.g., bright advertisements in tourist areas) can increase the BER and reduce the transmission rate during the day. At night, dimming the light intensity to save energy limits the average transmitted signal power, which may affect the communication distance [100]. One possible solution is using LED current overdriving at transmission with the help of VPPM [19,76,101]. Because VLC depends on LoS, on wide streets or in heavy pedestrian traffic, obstacles such as cars and trees can block the signal. This problem can be reduced by increasing the density of lighting fixtures, but this would increase the costs. Hardware integration requires street LEDs to be enhanced with high-speed (MHz range) drivers that are resistant to temperatures between −20 °C and +50 °C, vibrations and vandalism, which is a challenge in crowded tourist areas. Increased hardware complexity may also increase the failure rate, which, in certain scenarios, could affect not only connectivity but also the main illumination function. At the same time, maintenance requires access to tall poles, sometimes reaching 8–12 m, which involves extra costs. In conclusion, VLC challenges include optical interference, high deployment costs and limited standardization. However, all these can be overcome through hybrid solutions and smart retrofitting.

The authors of [13,79,93] highlight, in their research, that VLC is an important technology for smart tourist destinations because it provides security and high data rates through public lighting systems. This improves services that need real-time connectivity for tourists. In the hospitality sector, VLC transforms LED lights in hotels, museums and restaurants into data hotspots, offering Li-Fi for streaming and IoT devices without the interference problems that are common in RF communications. In smart tourist destinations, VLC supports TAN networks for mobile tourists and collects contextual data for personalization. Through OCC, VLC offers indoor positioning with high accuracy, helping tourists to find points of interest in museums using smartphone apps. It can also connect with big data systems for behavior analysis, increasing the efficiency of tourist destinations. In restaurants, VLC improves the visitor experience by showing interactive menus and enabling contactless payments.

Although large-scale commercial adoption is still developing, there are already real examples from tests and pilot projects presented in the recent academic literature that can be adapted to the tourism and hospitality industry. In 2020, a pilot project in smart hotels in Spain evaluated the use of VLC for automatic check-in: guests scanned the LED light at the reception desk with their phone camera and received digital room keys on their smartphones together with Wi-Fi/Li-Fi access in their rooms, significantly reducing check-in times [13,26,93].

A particularly interesting use case for VLC technologies is in museums and exhibition sites or even in commercial centers. Due to its impressive ability to provide dedicated location-oriented data communication services, VLC is suitable to provide users with

information regarding a particular objective. More importantly, differing from other technologies, the information can be continuously updated in accordance with the location of the user. The authors of [29,30] provide one of the first demonstrations of VLC use through the illumination of three-dimensional artworks in a real museum environment. In this work, lighting fixtures are used to both illuminate and emphasize the characteristics of the exhibits, while the reflected light is used to distribute information to tourists. The proposed concept was experimentally validated in a real museum in Florence using two actual three-dimensional exhibits. The results showed a communication range of up to eight meters, demonstrating the viability of the concept. The conclusions of this work indicate the potential of VLC technologies to enhance the visitor experience in museums and exhibition areas while reusing existing LED-based lighting systems.

In conclusion, the features of VLC highlight its strong potential to become an important technology in the tourism and hospitality industry. By unifying illumination, wireless communication and location services, VLC enables high-speed, secure, energy-efficient and location-aware services. In turn, these services can significantly improve the tourist experience in places such as hotels, museums or airports, transforming them into smart tourism destinations. The functions and benefits of VLC use in smart tourism applications are summarized in Figure 3.

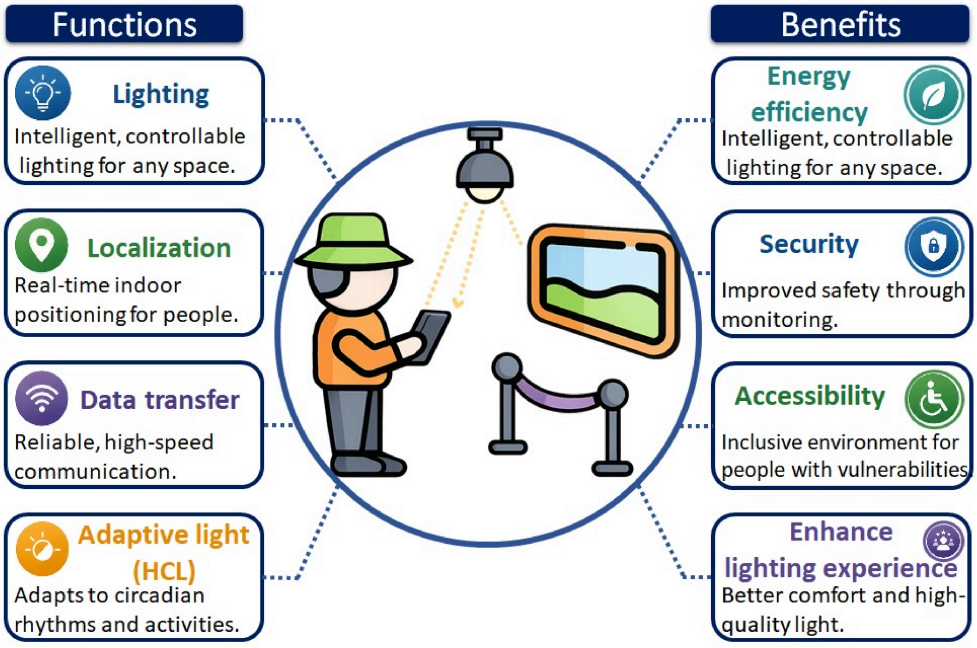


Figure 3. Summary of functions and benefits of VLC use in tourism applications.

5. Findings, Challenges and Future Directions

One can see that the main technical challenges in implementing VLC in tourism come from the optical nature of the technology, which limits transmission to closed environments. From this perspective, VLC suffers from LoS dependency, which could cause interruptions in high-mobility conditions such as hotel lobbies or museum exhibits. Other issues are related to limited coverage in large spaces, problematic handover when users move between APs and scalability in dense networks with a high number of tourists. Nevertheless, the research community and several private companies have already begun addressing these issues, enabling Li-Fi connectivity in mobile conditions, for multiple users, and in increasingly complex indoor and outdoor environments [34,35,46,101–103]. Here, hybrid VLC schemes with soft handover have been developed, with APs that coordinate simulta-

neous transmissions in order to avoid link interruptions. These results show the growing maturity of VLC technologies and emphasize their potential for large-scale deployment in future smart tourism and hospitality infrastructures.

From a different perspective, VLC deployment is being postponed because optical communication technologies are considered susceptible to interference from ambient light sources (e.g., sunlight, light bulbs). Although there is an intrinsic vulnerability that could lead to reduced bit rates and increased BERs, the technology has evolved significantly, and, today, existing VLC systems are able to cope with extreme optical noise conditions [34,35,47,101]. Thus, although the existing literature mentions optical interference as a major issue for VLC, there are numerous studies that have experimentally demonstrated that the impact of optical interference can be efficiently mitigated.

Another important aspect related to VLC technology deployment is the lack of a widely accepted standard. Although the IEEE 802.15.7 standard was released in September 2011, it has limited acceptance, and most VLC developers choose not to develop their prototypes in accordance with its specifications. Therefore, the lack of industry consensus contributes to higher costs and delays deployment. From this perspective, it should be emphasized that ongoing efforts are being made to develop improved and widely accepted standards that take into consideration new challenges and recent advancements in the VLC domain. As an example, motivated by the widespread use of cameras in mobile phones, the updated versions of the IEEE 802.15.7 standard include provisions for the use of cameras in VLC applications [104,105]. Toward this objective, future work should focus on integrating the perspectives of the academic sector, industry and standardization bodies within a framework that considers all important viewpoints and provides comprehensive unification through a widely accepted standard.

Nevertheless, arguably the most important factor involved in postponing VLC integration in tourism is the high initial costs. On the one hand, this comes from the cost of the electronics used to control the LEDs and receivers (i.e., photodiodes or cameras). On the other hand, the main part of the cost is associated with research and development (R&D), which will remain high per unit as long as the number of sold devices is low. However, these costs are expected to drop significantly once VLC technology is deployed and mass production begins.

Despite the numerous challenges, the implementation of VLC in tourism applications is motivated by important advantages. Analyses show the positive impact of VLC technology in the tourism and hospitality industry, with advantages related to security and data transfer speeds, but also disadvantages such as limited mobility, possible interference caused by ambient light, high initial implementation costs and a limited operating range. Nonetheless, the benefits show that VLC technology is a viable solution for sustainable tourism, with a strong potential impact in hotels and public attractions. Table 3 provides a summary concerning the impacts of VLC technology in the tourism and hospitality industry within some of the main use cases.

Regarding the comparison between VLC and Wi-Fi in hotels, it can be concluded that VLC, especially Li-Fi, offers better security than Wi-Fi in accommodation units because the light signal is limited to closed physical spaces. In contrast, Wi-Fi signals are spread in all directions, pass through walls and are vulnerable to external interception. While hotel Wi-Fi networks can be exposed to man-in-the-middle attacks and data sniffing on public networks, VLC partially removes these risks because it works based on an LoS approach, making hotels an ideal environment for implementation (see Table 4).

Table 3. The impacts of VLC technology in the tourism and hospitality industry.

Application Area	Benefits	Examples	Implementation Status
Hotels [13,24–26,33,79,80]	High security High data rate Improved energy efficiency	Automatic check-in Optical door lock Streaming in hotels	Conceptual application and early prototypes
Museums and exhibition areas [29,30,32,33]	Indoor guidance Location-aware communication services	Smart museum lighting Indoor positioning and navigation Location-based personalized content delivery	Pilot implementations with experimental demonstration Conceptual application
Smart cities and smart destinations [13,14,32,33,93]	IoT networks Interactive AR	Street lights broadband VLC traffic lights for tourists	Conceptual application Pilot implementation
Restaurants [13,79,96]	High-speed internet access Digital menus and context-aware services Location-based marketing	Location-based menu delivery Multilingual information services	Conceptual application and early prototypes
Aviation and smart transport [11,63–67,93]	No RF interference Lower weight High-speed onboard connectivity Reuse of existing lighting infrastructure Location-aware and personalized services	In-flight entertainment Passenger internet connectivity Aircraft IoT connectivity	Conceptual application, early prototypes, commercial solutions

Table 4. VLC vs. Wi-Fi security comparison in hotels.

Aspect	VLC	Wi-Fi	Advantage
Interception range	Within LoS, blocked by walls	35–100 m, omnidirectional	VLC (improved physical-layer security)
External attacks	More difficult outside the illuminated area (no wall penetration)	Man-in-the-middle, sniffing	VLC
Encryption	Physical encryption and Advanced Encryption Standard (AES) using 128 bits	WPA3 (still potentially vulnerable to implementation or configuration attacks)	VLC
DoS vulnerability	Local jamming	Deauthentication floods remote	Wi-Fi, resistant remote
Additional security cost	Zero additional security cost (included)	VPN mandatory	VLC

In hotels, VLC may reduce interference-related communication problems compared to congested public Wi-Fi networks [82], making it ideal for high-speed connectivity, check-in systems, in-room IoT devices and secure payments, although it requires LoS connectivity. Wi-Fi still remains necessary as a complementary technology to cover areas without direct visual connection.

Based on the reviewed literature, Table 5 provides a summary that shows the expected impacts of VLC adoption in tourism and hospitality. This summary highlights the

main application areas and the potential benefits associated with the deployment of VLC technologies in this sector. The analysis shows a potential increase in tourist satisfaction when VLC-based services are used, especially in smart destinations. In the tourism and hospitality industry, VLC also supports the automation of check-in operations.

Table 5. Expected impacts of VLC adoption in tourism and hospitality.

Area	Conventional Solutions	VLC-Based Solutions	Expected Benefit
Connectivity	Wi-Fi/RF	VLC/Li-Fi	Higher bandwidth, with existing commercial system providing 2Gb/s data rates [46]
Check-In Services	Near-field communication (NFC), QR codes	Optical authentication	Faster and more secure access [24–26]
Indoor Navigation	GPS unavailable indoors	VLC positioning	Higher positioning accuracy [12,16,48]
Security	RF-based networks	Restricted to optical coverage	Improved protection against eavesdropping [31]
Lighting	Illumination only	Illumination and communication	Improved energy efficiency [19,27,28,76,77]

The challenges and solutions related to VLC in the tourism and hospitality industry are presented below in Table 6. The main challenges include LoS blockage and limited coverage and mobility in open spaces. Integration with existing infrastructure also requires an initial investment, while receiving signals through smartphone cameras increases battery consumption. Another challenge is the lack of widely accepted and unified standardization, which slows down large-scale adoption.

Table 6. VLC challenges and solutions applied in the tourism and hospitality industry.

Challenge	Description	Potential Impact and Enabling Conditions	Solution
Blocked LoS	VLC requires direct visibility	Problems in crowded rooms	Hybrid VLC/Wi-Fi networks [82–85,90] Beamforming techniques [87–89]
Ambient interference	Other sources of light could affect the reception of optical signals carrying data	Open restaurants, open spaces, rooms with large windows	Optical filters, adaptive field of view (FoV), adaptive filtering and directional LEDs [34,35,47,101]
Mobility (tourists)	User mobility could generate connection loss	Walking tourists	Multi-AP with coordination, user mobility protocols [102,103], hybrid networks [82–85]
Scalability, standardization and cost	High initial deployment costs Limited large-scale commercial deployment Lack of widely adopted standards	Delayed deployment	Integration into existing lighting [19,27,28,76,77] Additional efforts toward widely accepted standardization [97–100] Technology popularization that can lower prices due to mass production

Lastly, it should be also mentioned that VLC technology has very good prospects in terms of users' acceptance. VLC operation is generally transparent and requires no changes in the ways in which communication services are accessed. Additionally, considering the growing concern about climate change and energy efficiency, VLC's multipurpose nature, which contributes to improved energy efficiency, could further contribute to its acceptance by users. Consequently, user acceptance is expected to depend primarily on the deployment cost, service availability and perceived benefits rather than on the technology itself.

6. Conclusions

This paper aimed to highlight a series of key recommendations designed to improve the future tourist experience using VLC technology. This communication system can help to provide the services requested by users, increasing tourist satisfaction through personalization. One major advantage is high-speed wireless connectivity, helping tourist attractions to become smart and sustainable destinations. It is estimated that the economic potential of the Li-Fi market will grow significantly in Europe [106], contributing to the transformation of the tourism sector.

VLC technology has shown strong potential to become very important for new 5G/6G networks. These networks are expected to experience substantial increases in data traffic volumes over the coming decades. Although the VLC market has not yet reached its full potential, the results analyzed in this research show that this technology could become an efficient complementary system for future 5G/6G wireless network development, both in terms of cost and energy consumption. It was observed that the initial price of a VLC system is high, but, compared to the operational costs, including energy consumption and maintenance, VLC could be a cost-effective long-term solution.

VLC offers greater economic and technical advantages than Wi-Fi in certain indoor hospitality scenarios because it can be integrated into existing lighting systems, although there are clear differences in cost and implementation. VLC uses the visible light spectrum for data transmission, offering an alternative to Wi-Fi in indoor environments such as hotels and museums. VLC also positions security as a competitive advantage in tourism by reducing common cybersecurity vulnerabilities in crowded hotels. VLC is transforming the tourism and hospitality industry through secure and efficient connectivity, with faster adoption in the hotel sector. Nevertheless, the future of this technology depends on widely accepted standardization, which in turn can provide faster deployment, improved costs and better scalability.

VLC has the potential to transform the tourism and hospitality industry through secure, continuous and fast connectivity, accelerating the development of smart tourist destinations. The academic papers analyzed confirm the strong potential of VLC in the tourism and hospitality industry, while also mentioning limitations such as ambient light interference and user mobility. Future research should focus on scalability and 5G/6G integration. Implementations from the last decade demonstrate the feasibility of this research and show significant economic potential.

In conclusion, one can say that VLC is becoming an important enabling technology in next-generation smart environments through smooth integration with IoT platforms and smart tourist cities, providing high-speed connectivity without RF interference, making it ideal for tourist attractions. In tourism, VLC accelerates the transition toward smart tourist destinations by improving personalized experiences, security and efficiency, with an estimated market impact of billions of dollars by 2030.

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G.Ț.; project administration, A.-M.C.; resources, A.-M.C.; supervision, A.-M.C. and G.Ț.; validation, C.-M.M., A.-M.C., C.B., E.Z., S.-A.A. and G.Ț.; visualization, A.-M.C. and S.-A.A.; writing—original draft, C.-M.M.; writing—review and editing, C.-M.M., A.-M.C., C.B., E.Z., S.-A.A. and G.Ț. All authors have read and agreed to the published version of the manuscript.

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Abbreviations

The following abbreviations are used in this manuscript:

GDP	Gross Domestic Product
VLC	Visible Light Communication
OWC	Optical Wireless Communications
RF	Radio-Frequency
LoS	Line of Sight
Wi-Fi	Wireless Fidelity
AP	Access Point
AI	Artificial Intelligence
Li-Fi	Light Fidelity
IoT	Internet of Things
VPPM	Variable Pulse Position Modulation
QoS	Quality of Service
HCL	Human-Centric Lighting
DoS	Denial-of-Service
KRACK	Key Reinstallation Attack
TRL	Technology Readiness Level
BER	Bit Error Ratio
AR	Augmented Reality
OOK	On–Off Keying
TAN	Tourist Area Network
OCC	Optical Camera Communication
R&D	Research and Development
AES	Advanced Encryption Standard
NFC	Near-Field Communication
QR	Quick Response
FoV	Field of View
LED	Light-Emitting Diode

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