Technological Innovation in Tourism 4.0: Exploratory Study of Technological Innovation in Tunisia's Tourism Ecosystem

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Abstract

This research explores innovations related to integrating Industry 4.0 technologies in the Tunisian tourism sector, focusing on transforming the user experience. In the context of the remarkable growth of Tunisian tourism, with more than 10 million visitors in 2024, innovation through digital technologies is becoming a critical economic lever for sectoral competitiveness and sustainable growth. Through an exploratory qualitative approach, twenty-one international economic and tourism experts, participating in the International Tourism Exhibition Oasien and Saharan (ISSOT 2024) in Tozeur, were interviewed during semi-structured interviews. The objective was to identify innovation opportunities and risks related to adopting advanced technologies (artificial intelligence, virtual reality, intelligent data management) in the tourism sector. The results reveal the potential benefits of this digital transformation in terms of innovation and improving user experience while highlighting the major challenges related to data security and skills adaptation. This study provides strategic insights to Tunisian tourism professionals to develop strategic innovation approaches integrating 4.0 technologies.

Keywords: Tourism 4.0, Tourism economics, Industry 4.0, Tourism Experience, Tourism Innovation, Tunisia.

Introduction

Rapid technological change has significantly transformed many sectors of the world economy, and substantially the tourism industry (Lima, Haro-Zea, & Saavedra, 2024). Indeed, the fourth industrial revolution, often referred to as "Industry 4.0", has profoundly changed the tourism landscape. The tourism sector, as an important pillar of the global economy, contributes significantly to employment, economic growth and development. It encompasses a wide range of activities, including transportation, accommodation, catering, attractions and entertainment (Chernenko et al., 2024; Gomes et al., 2024).

The fourth industrial revolution, or Industry 4.0, is transforming most industries and creating new challenges. This concept, initially presented in 2011 at the well-known Hannover Messe, is in the agenda of the high-tech strategy of German industry (Devezas et al., 2017). Web 4.0 possesses different features than the previous versions of the internet by enhancing instantaneous interaction between virtual worlds and humans and real-world objects that they interact with according to Kurgun, Aktas & Kurgun, 2018. Currently, humans and machines will be connected through smart, and wireless means to create interactions to collaborate and assist one another (Kurgun, Aktas & Kurgun, 2018). Industry 4.0 or the fourth industrial revolution (Schwab, 2017; Makiela, Stuss & Borowiecki, 2022) relies upon the integration of digital technologies, including

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artificial intelligence, big data analytics, robotics, the Internet of Things (IoT) and cloud computing. These technologies have disrupted established industries and enabled new avenues for innovation and efficiency (Kagermann & Winter, 2018; Hermann, Pentek & Otto, 2015).

There is not one single definition of Industry 4.0 as there exists a wide range of organizational and economic changes that may occur. As noted by Culot et al. (2020), the term covers a wide range of digital innovations, some of which are more extreme than others. The revolution is not only economic and technological but also involves social and cultural changes on a huge scale (Mazali, 2018; Gomes et al., 2024). Thus, it affects entirely different modes under which businesses operate through new forms of production and consumption, automation, digitization, and connectivity at an increased rate between systems and people (Jamwal et al., 2021).

As per Mordor Intelligence (2024), the worldwide COVID-19 pandemic has accelerated the pace of adoption toward Industry 4.0 and raised the awareness of resilience toward possible future pandemics. It is anticipated that the industry 4.0 market will grow from USD 94.42 billion in 2023 to USD 241.58 billion by 2028, thus depicting a CAGR of 20.67% over the forecast period, i.e., between 2023 and 2028. This accelerated adoption also redefined competition, changing established industries, particularly in the tourism sector (Peceny et al., 2019).

Some recent studies have tried to study the benefits and risks of this industrial revolution in the tourism sector. The results showed that Industry 4.0 has given rise to a new tourism paradigm, called "Tourism 4.0", which exposes how advanced technologies and digital innovations have changed the entire tourism sector. Technologies such as the Internet of Things, big data, artificial intelligence, virtual reality and augmented reality can be applied to the tourism sector, creating new models for economic value generation and capture (Peceny et al., 2019; Alexis, 2017).

Innovation in tourism is defined as the creation of new knowledge or the combination of existing knowledge to generate innovations in several dimensions: products, processes, organizational management, and digital transformation (Hjalager, 2010). As the tourism experience is shaped by a combination of services, products, destinations and interconnected local communities, tourism innovation is therefore largely influenced by the technological context (Yeh & Ku, 2019; Nguyen, 2024). Other research focused on the effect of Industry 4.0 on the tourism experience and showed that these technologies have a significant impact on the skills required and the composition of the global tourism workforce (Papathanassis, 2017).

Tunisia, as an emerging tourist destination, is not exempt from these dynamics. In 2024, the country recorded exceptional performances, both in terms of tourist attendance and revenues generated. The country has welcomed more than 10 million international visitors, setting a new record. Tourism receipts reached 7.2 billion dinars, a notable increase of 7.8% compared to the previous year (Khdimallah, 2024). At the same time, Tunisia has undertaken strategic initiatives to integrate Industry 4.0 into its tourism ecosystem. In December 2020, the country launched the HUB I4.0 initiative, which aims to accelerate the digital transformation of industries including the tourism sector (GIZ, 2020). Industry 4.0 competence centers, in partnership with the Fraunhofer IPA Institute, have been set up to help Tunisian companies adopt these new technologies (BMZ Digital, 2024).

However, despite the growing importance of digitization and Industry 4.0, little research is focused on how effective business models should be developed in tourism-related organizations

(Peceny et al., 2019). This research therefore aims to provide empirical evidence to the literature, focusing on two main pillars: Industry 4.0 technologies and organizational learning in the tourism industry.

The objective of this article is to identify and understand the perception of tourism experts and professionals about the effects of Industry 4.0 on tourism in Tunisia. More specifically, we will identify the benefits and risks of this technological evolution and its impact on the tourism experience. This study applies to the tourism industry (various tourism organizations engaged in the supply, promotion, sale, and purchase of tourism products) to achieve the highest productivity and ensure the sustainability of operations. It seeks to measure the impact of Tourism 4.0 and organizational learning on creating value-based digital transformation in the tourism industry.

Combining existing theoretical perspectives with empirical data from in-depth interviews with tourism experts, this research aims to contribute significantly to the understanding of the complex dynamics between technology and tourism in the Tunisian context. This may highlight interesting contributions for the sector specialists in terms of strategy and action plans capable of integrating the digital development of Industry 4.0 into the tourism activities of Tunisia.

In the first part, we will define the conceptual framework for the introduction of Industry 4.0 in the tourism sector and its effects on the tourist experience. We will then present the methodology, analyses, and results of the exploratory qualitative survey. Finally, we will discuss the results and present the managerial contributions.

Litterature Review

The evolution of technological transformation has been a story of greater storage and processing capabilities. Industry 1.0 marks the beginning of this progression, characterized by one-way communication and eventually giving way to the networking strategies of Industry 2.0. With Industry 3.0 arriving in 2015 and Industry 4.0 in 2020, this enabled a real co-construction of experiences and destinations (Larbi et al., 2021).

Web 4.0 is one of the latest evolutions in this evolution, enabling real-time interaction between the virtual worlds, humans and the physical things they interact with. In this age, humans and machines are establishing intelligent and cooperative relationships (Kurgun et al., 2018). Industry 4.0 is defined as applying the latest technologies including artificial intelligence, the Internet of Things, augmented reality and blockchain to improve the efficiency, personalization and sustainability of processes. Specifically, the industries of interest employ these technologies for real time data analysis, predictive maintenance, and streamlined supply chain management, which are essential in the overarching quest for better tourism services (Ivanov & Webster, 2024).

The pandemic has acted as an accelerator for Tourism 4.0." This metamorphose has led to the emergence of a new type of traveler, commonly known as the "digital tourist", who is defined by increased independence, enhanced capabilities and extensive use of ICT tools for traveling preparation, experience analysis and sharing (Benckendorff et al., 2020; Sotiriadis 2017). Such digital acceleration has concomitantly produced an increased demand for contactless solutions, virtual tours, and bespoke travel recommendations which has found very rapidly forced the industry of tourism to adopt digital innovations (Neuhofer, 2025).

According to Pencarelli (2019), tourism 4.0 is a paradigm applied in the shaping of highly technological services. It relies, among other things, on interoperation within systems, virtualization of services, decentralization of processes, real-time data handling, service orientation, and modularity of solutions. In the creation of value through enhanced user experience and sustainable practice adoption, tourism 4.0 highlights its relevance in an increasing consumer demand for responsible and tailored travel options(Neuhofer et al., 2015).

Tourism 4.0 technologies are radically transforming the tourist experience. The Internet of Things (IoT) connects everyday elements of the tourism experience such as luggage, hotel rooms and attractions, allowing for automatic classification that guides tourists' choices (see Table 1). Artificial intelligence analyzes data to personalize the user experience design, allowing travel services to learn from their interactions and optimize order processing (Hassani et al., 2020; Kazak et al., 2020).

Augmented and Virtual Reality creates immersive 3D environments combining visual, kinetic and audio elements, allowing virtual exploration of destinations for marketing, recreation and heritage preservation purposes (Kim et al., 2018; Vermaa et al., 2022). Big data generated by social networks and e-tourism sites facilitate the personalization of communication (Leung, 2022). Blockchain, based on distributed ledgers, impacts business models, payments, and security (Rashideh, 2020), while social media influences assessment and decisions via influencers' opinions (Pop et al., 2022).

These technologies allow the creation of sophisticated tourism products, reducing intangibility and uncertainty through simulations, virtual tours, and smart bookings (Gül & Gül , 2023). They also promote environmental, social, and economic sustainability (Fatema et al., 2024), allowing destinations to better understand the needs of tourists and optimize their resources (Shen & Sotiriadis, 2022).

The techniques	Definitions
Internet of Things (IoT) (Gao, 2020)	Connect everyday objects with internet devices, sharing their information online. In tourism, it connects luggage, hotel rooms, and attractions to improve the efficiency and personalization of services.
Artificial intelligence (AI) (Kazak et al., 2020)	Human-based system to analyze data, make decisions and personalize the user experience through continuous learning.
Augmented (AR) and virtual (VR) reality (Kim et al., 2018; Vermaa et al., 2022)	Creates 3D environments combining visual, kinetic and audio elements for virtual exploration of destinations and heritage preservation.
Big Data (Hassani et al., 2020)	Generates and analyzes huge amounts of data in real time via social networks and e-tourism sites to personalize communication.
Blockchain (Rashideh, 2020)	Distributed ledger technology for transaction recording, impacting business models and security in the sector.
Social media (Pop et al., 2022)	Assessment and sharing platforms influence decisions through the opinions of other travelers and influencers.

Table 1. Tourism 4.0 Techniques

Tourism 4.0 has many advantages and risks that need to be carefully analyzed. According to Rubino et al. (2021), these technologies fundamentally transform the way tourism services are produced and consumed. The Internet of Things provides better connectivity and personalization of the tourism experience by connecting luggage, hotel rooms, and attractions (Astanakulov et al., 2025). Artificial intelligence facilitates the analysis of large volumes of data to personalize the user experience (Kazak et al., 2020). Virtual reality enriches the visitor experience by allowing them to explore destinations before their trip virtually (Kim et al., 2018). The generated Big Data allows a direct connection with tourists and an optimal personalization of communication (Hassani et al., 2020).

However, these technologies also pose significant risks identified by Ghaderi et al., (2024). The main challenge is related to the cybersecurity and personal data protection of tourists. The authors also highlight problems of standardization between different systems and the lack of digital skills of staff. The digital transformation also requires significant financial investments, particularly problematic for small structures. Kumar & Kumar (2022) also highlight the risks associated with technology dependency and the digital divide between actors. Nevertheless, as Pencarelli (2020) pointed out, these technologies create real added value for tourists by helping them make better decisions through their enriched experience.

The tourism experience has undergone a profound transformation with the advent of Industry 4.0 technologies. Traditionally associated with everyday escape and experiential learning (Brougère, 2012), it now incorporates an important digital dimension that fundamentally changes consumer perceptions and behaviors (Shuquair & Gragg, 2017). According to the theoretical framework developed by Pine and Gilmore, the tourist experience is structured around four fundamental dimensions: entertainment, which aims to evoke positive emotions, aesthetics, centered on stimulating the senses, education, based on the transmission of knowledge, and escapism, allowing an immersion in imaginary universes (Mehmetoglu & Engen, 2011).

This study is based on the theory of active learning, which assumes that learners build their knowledge more effectively when they are actively involved in the learning process (Bonwell and Eison, 1991). In this context, Industry 4.0 acts as a facilitator by providing tools that encourage active engagement, allowing tourists to participate more actively in their tourism experience rather than being passive consumers.

In this new paradigm, tourism destinations and industries collaborate closely to design and deliver intelligent experiences for travelers (Shen & Sotiriadis, 2022). Tourists are no longer passive consumers but have become active co-creators of their experience, using digital technologies to plan their trips, communicate with providers, and share their recommendations with other travelers. Technological innovations such as virtual and augmented reality greatly enrich the experience at all stages of the tourism journey, offering increased possibilities for interactivity and immersion (Fan et al., 2022).

However, this growing digitalization of the tourism experience also poses significant challenges. The ubiquity of technologies can create confusion between the use of digital tools and the authentic experience of travel , potentially generating technological stress, a certain information overload, and dehumanization of the tourist experience (Buhalis et al., 2019). The researchers point out that Tourism 4.0 sometimes tends to favor technological efficiency at the expense of a truly human-centered approach (Pencarelli, 2019).

This technological evolution has also led to the emergence of a more complex tourism ecosystem, involving a multitude of actors ranging from public authorities to social network influencers through traditional service providers. This reconfiguration profoundly changes the operating modes and responsibilities of each stakeholder within the industry. The major challenge now is to find a balance between technological innovation and preserving the authenticity of the tourist experience while guaranteeing the protection of personal data and respect for the privacy of travelers (Ivanov et al., 2024).

Finally, Industry 4.0 is profoundly transforming tourism jobs through different technologies that change the nature of work, as Pencarelli (2020) pointed out by identifying supplementary, substitute and palliative technologies. These innovations strengthen both the technical and interpersonal skills of employees while optimizing the operational management of tourism businesses. Technologies such as AI, virtual/augmented reality and IoT improve operational efficiency and asset management , allowing for a better understanding of tourists' needs and facilitating co-tourism value creation between the sector's stakeholders.

Methodology

An exploratory qualitative approach was adopted, justified by the emerging nature of research on tourism 4.0 in Tunisia. This methodology was chosen for its ability to identify and explore a problem and its different aspects in a context where previous studies are limited (Shaw, 1999). Data collection was carried out through semi-directional interviews, aligned with the constructivist paradigm (Lincoln, 1995), allowing a thorough understanding of the perception of actors regarding industry 4.0 in the tourism sector.

Incremental convenience sampling was used, following the methodology of Guillemette et al. (2006). The interviews were conducted at the International Tourism Exhibition for Oasians and Saharans (ISSOT 2024), held in Tozeur from 3 to 5 December, bringing together nearly 500 participants, including journalists, influencers and tour operators from 14 countries.

The study includes 21 participants, selected until information saturation is reached. Table 2 summarizes the **characteristics of participants.**

Num.	Function	Age	Kind	Nationality
1	Travel agency manager	45	Male	Tunisia
2	Tourism marketing consultant	38	Female	Morocco
3	Hotel manager	50	Male	France
4	Journalist specializing in tourism economies	34	Female	Spain
5	Travel Influencer	29	Female	Italy
6	Tour operator manager	42	Male	Germany
7	Expert in digital marketing and social networks	37	Female	Tunisia
8	Head of tourist association	55	Male	Algeria
9	Professor of tourism economies	48	Male	Egypt
10	Travel blogger	31	Female	United Kingdom
11	Digital marketing and online campaigns consultant	46	Male	Belgium
12	Event Manager	40	Female	Tunisia
13	Freelance journalist	36	Male	Italy

14	Nature Park Manager	52	Male	Canada
15	Tourism Project Manager	33	Female	Switzerland
16	Expert in digital communication and influence	39	Male	Tunisia
17	Marketing manager of an agency	28	Female	Spain
18	Tourism economic strategy consultant	44	Male	France
19	Head of International Relations	41	Female	Germany
20	Professor of tourism technology	47	Male	Morocco
21	Researcher in Smart Tourism	53	Male	Tunisia

Table 2. Participant characteristics

A structured interview guide, based on existing literature, has been developed to explore the following themes: perception of tourism 4.0, technologies used, perceived benefits and risks, impact on user experience, and future perspectives. The interviews were recorded in audio to allow for accurate transcription. Each interview was held in a calm environment, guaranteeing the confidentiality of the exchanges. The average interview time was 35 minutes, ranging from 30 to 40 minutes. The collection continued until information saturation was reached, with a total of 21 interviews.

In this research, particular attention was paid to the ethical aspects of interviews with experts. Prior to each interview, informed consent was obtained from participants. They were given a detailed explanation of the objectives of the study, its conduct and the potential implications of their participation. Participants were informed of their right to withdraw at any time, without any justification. The anonymity and confidentiality of the data collected have been strictly respected in order to guarantee the protection of the information shared.

To ensure the reliability of our analysis, we used a two-tier triangulation strategy (Lincoln & Guba, 1985). The methodological triangulation was achieved by combining interview data with observation notes taken at the time of interviews, thus allowing to capture non-verbal cues and immediate reflections. The triangulation of data sources was achieved through the diversification of participant profiles (twenty-one experts from different nationalities, specialties and genders), allowing a cross-checking of the identified themes.

Results

Our main objective is to study in depth the perception of tourism actors about the likely effects of industry 4.0 on tourism in Tunisia.

In addition, the 4.0 tourism design was illustrated in a global cloud (Figure 1).

Figure 1. Tourism 4.0 word cloud representation

Theme	Sub-themes	Evidence: textual comments from respondents
Perception of Tourism 4.0	Approach that integrates technology	"Tourism 4.0, integrates digital technologies such as artificial intelligence (AI), virtual reality and advanced connectivity." int1
	Personalization of the experience	"Tourism 4.0 is completely reinventing the travel experience by leveraging digital advances to offer more individual and connected travel." int6
	Sustainable tourism	. And which also incorporates notions of sustainability, it is tourism that also thinks about ecology . » int17
	Adoption	"Many companies are integrating tourism 4.0 into their strategies, highlighting its importance as a driver of innovation"
	Change in experience	"The tangible effects of tourism 4.0 on improving travel experiences are consolidating its position as a major trend". int16
	Process change	"Tourism 4.0 is seen as a major trend in the travel and tourism industry, changing the way travelers book, plan and experience their trips through the growing use of digital technologies and personalization." int1
	Enthusiasm	"Some tourism professionals' welcome tourism 4.0, being enthusiastic about the opportunities offered by new technologies." int6
	Concern	"Some may express concerns about the potential dehumanization of services, highlighting the importance of human contact in the tourism industry." int13
	Response to expectations	"The perception of tourism 4.0 as a major trend is reinforced by its ability to meet growing user expectations for technology." int14

Table 3. Themes and sub-themes

The results of the interview on the perception of tourism 4.0 reveal a positive orientation towards this major development. Tourism stakeholders have clearly expressed their openness to a

"technology-integrated approach", highlighting an appreciation of the opportunities that technology can offer in the tourism sector. The preference for "Experience Customization" is striking, indicating a growing demand for tailor-made travel tailored to individual preferences. "Sustainable tourism" is emerging as a central concern, indicating an increasing awareness of environmental issues. The results of "Adoption" suggest a widespread acceptance of tourism 4.0 by businesses, indicating a tendency to rapidly embrace these innovations. Participants positively viewed the "Experience Change" as an overall improvement in travel experiences. The "Enthusiasm" category is high, while significant concerns are expressed in the "Concern" category. Finally, the "Response to expectations" varies, highlighting a diversity of opinions about satisfaction with initial expectations. These results provide crucial insights into how the sector perceives tourism 4.0 and highlight key aspects that could shape the future of travel.

Theme	Sub-themes	Evidence: textual comments from respondents
Most Frequently used techniques	Digital application	"Apps like Airbnb and Booking.com make it easy to find and book accommodation around the world". Int3
	IoT connectivity	The integration of connected objects in hotels, such as smart room control devices or intelligent energy management systems. int15
	Cryptocurrency	"Dubai is exploring the use of blockchain in the hotel sector to ensure payment security and boost traveler confidence." int13
	Artificial Intelligence (AI)	"Artificial intelligence in the field of tourist booking Big data in data management in tourism companies." int18
	Digital payment	"The adoption of digital contactless payment systems and e-wallets for faster, more secure transactions while traveling." int16
	Virtual Reality (VR) and Augmented Reality (AR)	"Using virtual and augmented reality to create immersive experiences, virtual tours, and contextual information while on the go." int1

Table 4. Most Frequently used techniques

The analysis of the techniques most used in the context of tourism 4.0 reveals a dynamic and diversified landscape. Digital applications are emerging as a dominant solution, underlining the growing importance of interactive platforms in the travel industry. IoT (Internet of Things) connectivity is also emerging as a widely adopted practice, denoting the extensive use of interconnected devices to optimize traveler experiences. Cryptocurrency, as a medium of

dematerialized financial transactions, is making its entrance in a significant way, reflecting a transition to more modern and secure payment methods. Artificial Intelligence (AI) is central, playing a key role in personalizing travel experiences and providing smart recommendations. Digital payments are generally being widely adopted, simplifying and securing transactions. Virtual Reality (VR) and Augmented Reality (AR) are also essential tools to create immersive and innovative experiences for travelers. These results highlight the rapid transformation of tourism through the integration of these advanced techniques, offering crucial perspectives to anticipate future developments in the sector.

Theme	Sub-themes	Evidence: textual comments from respondents
Benefits of tourism 4.0	Decision support	"Advanced data analytics provided by Tourism 4.0 help us make more informed decisions by understanding market trends and traveler behaviors."
	Increase in user engagement	"It's about delivering more personalized and responsive user experiences, enhancing satisfaction and loyalty."
	Increase competitiveness	"By adopting tourism 4.0 technologies, competitiveness can be enhanced by staying up to date with the latest trends and offering innovative services compared to the competition."
	Minimization of costs	"Tourism 4.0 technologies, such as process automation and data management, help optimize operations, reduce costs and improve efficiency."
	Optimization of communication	"Improve online visibility through digital marketing strategies and social media presence."
	Optimization of targeting	The main advantages of Tourism 4.0 for tourism professionals are the organization of their service through advanced software of these technologies and also understanding their target as they need to better offer a good service study in a well limited time.
	Personalization of user experiences	"Tourism 4.0 offers business and marketing opportunities such as customizing offers and developing unique experiences."

Table 5. The Benefits of tourism 4.0

The results of the interviews on the main theme "Benefits of tourism 4.0" highlight several significant positive aspects. The responses from tourism stakeholders highlight that decision support is emerging as one of the predominant advantages, highlighting the ability of Tourism 4.0 to provide crucial information to support informed choices for travelers.

Increased user engagement is clearly identified as a significant benefit, indicating that technological advances contribute to improving the overall travel experience. At the same time,

responses from tourism stakeholders suggest that the pursuit of greater competitiveness is a key motivation, indicating that tourism 4.0 is perceived as a means to ensure relevance and competitiveness in the sector.

Cost minimization is a notable benefit, highlighting the economic efficiency associated with adopting 4.0 tourism practices. The optimization of communication is also noted, indicating an improvement in the exchange of information between the different actors of the tourism industry.

Targeting optimization is emerging as a clear trend, underlining the ability of 4.0 tourism to more effectively reach specific audiences and meet their unique needs. Finally, the responses from tourism stakeholders indicate that the personalization of user experiences is identified as a major advantage, highlighting the ability of Tourism 4.0 to create tailor-made trips tailored to individual preferences.

These results substantially highlight the perceived value of Tourism 4.0, highlighting the multiple benefits it brings to both businesses and travelers. They provide essential information to understand the reasons for the growing adoption of these technologies in the tourism sector.

Theme	Sub-themes	Evidence: textual comments from respondents
Risks and challenges:	High implementation costs	"The need to train staff can present financial challenges." int11
	Dependence on technology	"Adoption of Tourism 4.0 could involve risks such as an excessive reliance on technology"
	Resistance of stakeholders	"Employees and users can resist change, unfortunately"
	Security Risks	"Risk of cyber-attacks and sensitive client data leaks"
	Unethical use	"Perhaps unethical use of tourism 4.0 tools" int20

Table 6. Risks and challenges

The responses of tourism stakeholders during the interviews on the main theme "Risks and challenges" highlight several important concerns related to the adoption of tourism 4.0 in the world and more specifically in Tunisia. The high implementation costs present themselves as a major challenge, highlighting the financial difficulties that companies may encounter when integrating these new technologies.

Technology dependency emerges as another significant challenge, highlighting the potential risks associated with increasing reliance on complex digital systems. The responses from tourism stakeholders indicate that resistance from stakeholders is also a significant barrier, highlighting challenges in managing change and persuading various stakeholders to be effective and relevant

for tourism 4.0.

Security risks are clearly identified as a concern, highlighting data protection concerns and the potential vulnerability of systems to cyber-attacks. In addition, unethical use is raised as an ethical challenge, highlighting the need to implement responsible practices in the development and application of tourism 4.0 technologies.

These results reveal a nuanced perception of the risks and challenges associated with the evolution towards tourism 4.0, offering important perspectives for the tourism industry. They stress the need to take these critical aspects into account when implementing these new technologies to ensure a successful transition to tourism 4.0.

Theme	Sub-themes	Evidence: textual comments from respondents
Effects on the tourism experience:	Sensory and aesthetic aspects of the experience	Virtual reality creates an environment with which the user can interact. Virtual reality therefore artificially reproduces a sensory experience, which may include sight, touch, hearing and smell (visual, auditory or haptic). int18
	Entertainment	Wearable devices such as smartwatches and smart glasses can enrich leisure by providing real-time information. int11
	Education and knowledge enrichment	Applications offer thematic tours focusing on educational aspects such as architecture, art or local history.
	Escapism	"VR simulates destinations to help travelers choose their next adventure." int10

Table 7. Effects on the tourism experience

The main theme "Effects on the tourism experience" and its sub-themes were used to gather responses from stakeholders in the tourism sector, providing a deeper perspective on the impact of technology on travel, and more particularly on tourism experiences in Tunisia. From a sensory and aesthetic perspective, virtual reality is distinguished by artificially reproducing immersive sensory experiences, ranging from sight to touch, creating innovative visual, sound, and haptic experiences.

In the entertainment arena, wearables such as smartwatches and smart glasses are proving to be enriching tools, providing real-time information to enhance travelers' leisure. In terms of education and knowledge enrichment, applications for educational tours focusing on architecture, art, and local history are identified as essential contributors to traveler learning.

In terms of escapism, virtual reality is emerging as a powerful means to simulate destinations, offering travelers pre-discovery virtual exploration to help them choose their next adventures.

These overall results reflect the diversity of potential benefits of technology in shaping more immersive, educational, and personalized tourism experiences. They highlight how tourism 4.0, through aspects such as virtual reality and wearable devices, is significantly transforming the nature of travel, Providing industry players and travelers with a rich range of opportunities and innovative experiences.

Theme	Sub-themes	Evidence: textual comments from respondents
Prospects:	Ecological tourism	"In my view, tourism will be more environmentally friendly."
	More efficient tourism	"With tourism 4.0 I think all the problems that are related to papers and signatures disappear and replace them with other more effective solution." Int12

Table 8. Prospects

The discussions on the central theme "Perspectives for the future" revealed promising prospects for the world and more specifically for Tunisia. The responses from stakeholders show that "ecological tourism" is emerging as a dominant vision, highlighting the growing commitment to environmentally friendly practices. Tourism stakeholders are expressing a strong interest in sustainable approaches, reflecting a growing awareness of the environmental issues in the sector.

Another key perspective that emerges is that of "more efficient tourism". Responses from stakeholders show a commitment to maximizing operational efficiency and the judicious use of resources. Industry actors seem to anticipate innovative approaches to making the industry more efficient, in the context of constant technological change.

These results provide a positive and forward-looking view of the future of tourism, showing a transition to more environmentally friendly practices and a quest for greater efficiency within the industry. These perspectives of the future are shaping a landscape where tourism is redefining itself through sustainability values and proactive adaptation to technological developments. This context suggests an encouraging trajectory for the travel industry, aligned with ethical principles and driven by innovation.

Discussion

The rapid evolution in tourism, particularly with the emergence of tourism 4.0, is a profound change in the way the travel industry operates, and in this study, our main objective is to deeply investigate the perception of tourism sector actors about the likely effects of Industry 4.0 on tourism in Tunisia.

The results of our study are in line with recent research findings in this field. Buhalis et al. (2024) highlighted the importance of perceived learning value and satisfaction in adopting 4.0 technologies. They also highlighted the critical role of systems and information quality in user acceptance of these technologies.

The variety of responses from stakeholders in the sector illustrates a complex landscape of

perceptions and attitudes towards the emergence of tourism 4.0 in Tunisia. Some seem to be optimistic about the opportunities it offers, seeing substantial improvements in the personalization of tourism experiences and overall competitiveness of the sector. this result is consistent with the results of previous studies by Stankov and Gretzel in 2020.

This perspective is reinforced by the work of Jain et al. (2023), which demonstrated that perceived utility and ease of use are determining factors in the adoption of 4.0 technologies. Furthermore, Al Al-kfairy (2024) highlighted the importance of performance and effort expectations in the adoption process, highlighting the need for a balanced approach between technological innovation and ease of use.

The author suggests that tourism 4.0 is a new ecosystem of tourist value, allowing for improved interaction with a system and enrichment of the tourism experience itself, offering new ways to help change behavior and even the sustainable transformation of users for a more immersive and personalized travel experience.

Others, on the other hand, take a more cautious approach, highlighting concerns about the necessary adjustments and potential implications for employment in a specific Tunisian context. Understanding these nuances is crucial to guiding implementation and adoption strategies.

The economic dimension of Tourism 4.0 is also of significant importance, because these technologies remodel value chains and contribute to creating new economic models in which new data become a strategic asset for a competitive advantage in the Tunisian tourism market.

The identification of major technologies, including artificial intelligence, virtual reality as mentioned by Kasak et al, 2020, and IoT connectivity (Gao, 2020), highlights the need for proactive adaptation of the Tunisian tourism sector. These technologies are not simply technological innovations but drivers of socio-cultural and economic change. In this context, our findings are similar to those of Salloum et al. (2024), who highlight the importance of a comparative approach between different technologies to optimize their integration into the tourism sector. The issue of accessibility and adoption of these emerging technologies should be addressed holistically to ensure a smooth transition.

The tangible benefits of tourism 4.0 are expressed through interviews, highlighting aspects such as decision support, increased user engagement, and minimization of costs. However, these benefits are accompanied by risks and challenges as human-system interaction issues have arisen, leading to various difficulties or abuse of use (Weaver & Moyle, 2019). Also, technological stress, information overload, depersonalization and dehumanization of tourism experiences, human rights abuses, perception of risks associated with the use of technology and, ultimately, the degradation of the value of the tourism experience (Dinçer & al., 2020), while adding implementation costs and cybersecurity concerns, require special attention. The management of these challenges should be aligned with the specificities of the Tunisian ecosystem, integrating cultural values and societal aspirations.

The results of our in-depth survey reveal a substantial transformation of the tourism experience in Tunisia under the influence of tourism 4.0. Beyond the incorporation of advanced technologies, this evolution fundamentally remodels how visitors interact with Tunisian heritage, culture and sites.

First, the data indicates that tourism 4.0 transcends the mere technological aspect, placing travelers at the heart of co-creating their experience, as indicated by Shen & Sotiriadis, 2022,

digital technologies are changing the game to deliver intelligent experiences for travelers. The use of virtual reality, for example, offers immersive interaction opportunities, allowing a deep engagement with local history and culture. This finding is consistent with the authors Schuemie, Van Der Straaten, Krijn & Van Der Mast, 2001, who show that VR and AR offer increased interactivity as well as enhanced sensory immersion opportunities. Also, the results of Vermaa & al, 2021, where the author explained that visitors have the opportunity to explore various virtual reality applications developed for purposes such as marketing, recreation, learning, accessibility and preservation of heritage.

Instant connectivity provides travellers with a personalized, fun experience, keeping them informed of events and points of interest while on the move. According to our findings, tourism 4.0 increases the depth of the tourist experience by providing relevant cultural and historical information, thus transforming travel into a learning opportunity and allowing them to plan and choose their next adventures in an immersive way, adding a dreamy dimension to the planning phase of the trip.

The "Future Perspectives" of tourism 4.0 reveals two major trends in our study. First, "Ecological Tourism" emerges as a priority, showing an increasing commitment to environmentally friendly practices. Then, the aspiration for "More Efficient Tourism" emerges, highlighting the desire to optimize operations and the use of resources. These perspectives suggest a positive evolution towards sustainable and efficient tourism, reflecting an increased awareness of ecological issues and adaptation to technological advances.

Despite the contribution of our research, we have identified some limitations. First, the gender distribution of respondents was unbalanced, with 62% women and 38% men among participants. Furthermore, given that our study is exploratory, it is necessary to undertake a more in-depth validation through a quantitative study.

Conclusion

The literature review on tourism 4.0, particularly in Tunisia, highlights the lack of extensive research into the effects of this technological revolution on the tourism sector. This study aims to fill this gap by analyzing the perceptions of industry stakeholders about the opportunities and challenges related to tourism 4.0. Through semi-structured interviews, the results obtained show that tourism 4.0 is perceived positively by experts, who recognize its potential to transform the tourist experience, improve operational efficiency and strengthen the sector's competitiveness.

Economically, Tourism 4.0 contributes to new sources of income and new business models that could promote the economic development of Tunisia beyond the tourism sector itself.

Emerging technologies such as artificial intelligence, virtual reality and intelligent data management are seen as levers to deliver more personalized and immersive experiences. However, there are still concerns, particularly regarding data security and the adaptation of professionals' skills to new technologies.

Managerial Implications and Recommendations

The tourism sector in Tunisia must adopt adaptive management strategies to integrate 4.0 tourism technologies. It is essential to promote a collaborative and proactive approach, involving the different actors in the sector, in order to maximize the benefits of these technologies. Investments in cybersecurity are important to preserve data privacy and build consumer confidence. In

addition, to fully exploit the potential of emerging technologies, it is essential to strengthen employees' continuing training, thus enabling them to adapt to new digital requirements.

In addition, our results highlight the importance of a balanced approach between technological innovation and the preservation of the authenticity of the tourism experience. Tunisian tourist destinations must develop a coherent digital strategy that integrates 4.0 technologies while preserving their unique cultural identity.

International experts show a strong interest in tourism 4.0 innovations, including immersive experiences, which open up opportunities for the enhancement of tourist destinations and the creation of richer, more personalized relationships with travelers. The potential economic and social benefits of this development are considerable, contributing to the competitiveness of the tourism sector on a global level. Tourism organizations need to adopt a human-centered approach to their digital transformation, ensuring that technology improves rather than replaces human interaction.

Although this study provides significant insights, some methodological limitations must be considered in the interpretation of results. The qualitative nature of the research and the small size of the sample suggest caution in generalizing conclusions. These limits open up promising new research opportunities.

Future research could take a longitudinal approach to analyze the temporal dynamics of changing tourism behavior in the face of 4.0 technologies. Additional quantitative studies, such as surveys to capture global trends or experimental designs to assess real impacts, could provide more in-depth insights. In addition, the exploration of moderating variables such as cultural context and social norms would enrich the understanding of the mechanisms that transform knowledge into actions.

It would also be appropriate to examine strategies for integrating innovative technologies while addressing associated risks. This approach opens the way for studies on the role of emerging technologies in sustainable tourism management. In addition, research could focus on the impact of these technologies on tourist satisfaction, long-term user engagement and skills required in a changing sector.

Finally, it would be interesting to explore how tourism stakeholders can collaborate to build an integrated digital ecosystem that benefits all stakeholders while preserving the authenticity of tourism experiences.

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