



Digital technologies and economic performance of Italian museums

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Abstract

This paper investigates the relationship between the adoption of digital technologies and the economic performance of Italian museums. We build a novel dataset with microdata for the near-universe of Italian museums in 2018 and 2022, enriched with municipal-level information on economic conditions, tourist flows and transport infrastructure. Our analysis highlights distinct economic roles for different classes of digital technologies. We find that while *digital supports*, such as interactive displays and mobile applications, are mainly associated with increased museum visits, *web services*, particularly online ticketing, primarily contribute to higher revenue. In contrast, *remote-access tools*, such as virtual tours, are generally associated with lower on-site revenue, suggesting a partial substitution away from paid visits. We then show that governance structures and infrastructural accessibility significantly *moderate* these relationships. Notably, directly managed museums, public institutions and those located in remote areas benefit the most from digital investments. These results emphasize the importance of tailored digital strategies, aligned with institutional characteristics and broader contextual factors, to enhance the economic performance of Italian museums.

Keywords Museums · Digital innovation · Economic performance

JEL classification L33 · O33 · Z10 · Z32

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1 Introduction

Cultural heritage is recognized as a strategic asset that contributes significantly to the socio-economic development of the European Union (EU) (European Commission, 2023). Its ability to enhance urban and rural attractiveness, stimulate investment and foster skilled employment makes cultural heritage a vital asset for economic value and innovation (Capello et al., 2020). Among cultural institutions, *museums* play a crucial role due to their unique dual mission: preserving cultural, artistic and historical artifacts while providing educational and engaging experiences to the public (Falk et al., 1998; Kotler & Kotler, 2007; Arnaboldi & Lema, 2021; Agostino & Arnaboldi, 2021). This dual nature makes museums essential drivers for cultural tourism and local development.

The recent development and integration of *Information and Communications Technologies* (ICTs) has transformed the way museums deliver and enhance visitor experiences, consequently affecting their economic potential (Gómez-Zapata et al., 2018; Elgammal et al., 2020). Digital innovations such as interactive displays, mobile applications and online virtual tours have opened up new forms of visitor engagement, offering museums the opportunity to develop new business models and revenue streams (Coblence & Sabatier, 2014; Güner & Gülaçıt, 2022). Although several studies have explored how digital technologies improve educational and social engagement (Federici & Parisi, 2022; Pérez-Sanagustín et al., 2016), as well as the determining factors of their adoption (Leoni & Cristofaro, 2022; Tham et al., 2025), the impact of different ICTs on museums' economic performance remains relatively understudied.

This paper fills this gap. We build a novel dataset by matching two waves of microdata from the Italian Institute of Statistics (ISTAT) covering the near-universe of Italian museums in 2018 and 2022. The dataset is further augmented with municipal-level information capturing economic, touristic and infrastructural characteristics. Using the latter, we document the distinct economic roles of different classes of digital technologies. Specifically, we find that while *digital supports*, such as interactive displays, are mainly associated with an increase in museum visits, *web-based services* such as online ticket sales and social media presence are closely linked to higher revenue.

Finally, we show how institutional and local context factors *moderate* these relationships. Notably, directly managed museums, public institutions and those located in remote areas benefit the most from digital investments.

The paper is organized as follows. Section 2 reviews the existing literature. Section 3 presents the conceptual framework guiding the analysis. Section 4 introduces the empirical strategy, describes the data 4.1 and reports the cross-sectional 4.2 and panel estimates 4.3. Section 5 investigates how the relationships between digital technologies and museum performance vary according to their management structure, ownership type and infrastructural accessibility. Finally, Sect. 6 concludes by summarizing the main findings 6.1, translating them into concrete managerial guidance and quantitative benchmarks for cultural practitioners 6.2, and outlining directions for future research 6.3.

2 Literature review

The role of cultural heritage has evolved significantly in policy frameworks, from the recognition of its intrinsic cultural and historical value (UNESCO, 1954) to its contemporary role as a strategic resource driving economic development and social cohesion (Council of Europe, 2005; European Commission, 2024). Museums, given their dual mission of preserving artifacts and engaging the public through structured educational experiences, have become crucial in promoting cultural tourism, thus favoring local economic growth (Sandell, 2003; Longo & Faraci, 2023). As a result, the integration of *digital technologies* in museum activities is an area of growing academic interest.

The adoption of *digital technologies* in museums has been recognized for improving both the visitor experience and operational efficiency (Navarrete, 2013; Schweibenz, 2019; Xie, 2022; Agostino, 2024; Tham et al., 2025). Digital integration facilitates a range of activities, from streamlined operations and increased accessibility of exhibitions to more personalized interactions with visitors, which collectively contribute to the museum's long-term sustainability.

Digital supports, such as mobile applications, digital displays and QR codes, directly enhance on-site visitor experience by providing dynamic and educational contents that are both engaging and easily accessible. These tools allow for a deeper immersion in the thematic contexts of the exhibitions, encouraging visitors to explore the museum's offerings more thoroughly (Pérez-Sanagustín et al., 2016; Federici & Parisi, 2022; Trunfio et al., 2022). Such interactions not only improve visitor satisfaction, but also increase the likelihood of recommendations and repeat visits, which are vital metrics for a museum's success (Brida et al., 2014, 2016b, a, 2017). Therefore, the impact of these technologies can be particularly pronounced in museums with interactive or contemporary exhibitions, where digital media are easily integrated to complement and enhance the physical objects on display (Gronlund, 2016; Van Saaze et al., 2018).

In contrast, *web services* aim to extend the reach and accessibility of museum collections beyond physical boundaries, thus broadening the potential audience (Pencarelli et al., 2017; Sylaiou et al., 2017; Tham et al., 2025; Xie, 2022). These services, which include virtual tours, provide alternative revenue streams through premium experiences and subscription models (Hume & Mills, 2011; Kabassi et al., 2019). For these reasons, they are particularly advantageous for museums located in areas with lower tourist traffic or for those that house fragile collections that are difficult to exhibit in physical settings. By offering online content, museums can also engage with international audiences, encourage educational outreach and promote the appreciation of cultural heritage (Grincheva, 2018). In addition, online ticketing systems simplify the booking process and visitor entry, as well as support dynamic pricing strategies and effective visitor flow management, thereby improving both the visitor experience and revenue potential (Devine & Tarr, 2019).

Previous research shows that the adoption of ICT is significantly influenced by factors such as *governance structures and ownership models* (Bertacchini & Morando, 2013; Camarero et al., 2011; Turrini et al., 2008). The type of institution also plays a significant role; in fact, museums dedicated to science and contemporary art are

often more innovative and quicker to integrate new technologies (Museum, 2021; Tham et al., 2025). For example, O'Hare (2015) emphasizes that art museums could particularly benefit from competent management of the resources with which the society has endowed them, reinforcing the idea of digital tools as a means to optimize resource use and improve visitor engagement according to both rational and ethical considerations.

Governance is particularly crucial when museums strive to balance their educational mission with financial sustainability. For instance, public museums typically adopt digital tools to improve accessibility and educational outreach, in line with their public service mission, while private museums mostly use these technologies to increase profitability and attract a wider paying audience (Coblence & Sabatier, 2014). Similarly, directly managed institutions can benefit more from ICT investments thanks to a greater alignment between the use of technology, their strategic objectives and operational strategies, facilitating a more effective and integrated use of digital resources (Di Liddo et al., 2023).

Finally, the literature suggests that the effectiveness of ICT strategies in promoting cultural tourism is influenced by the *availability and quality of transport infrastructure* (Khadaroo & Seetana, 2007). Museums located near major highways, train stations or airports can take advantage of these transportation hubs to increase the number of visits. In particular, accessible highways attract more national and local tourists, thus increasing the economic benefits of cultural tourism (Percoco, 2016). Similarly, proximity to train stations and airports makes museums more accessible to international tourists, who are more likely to visit them thanks to the ease of travel and the prospect of cultural experiences, often amplified by digital platforms (Peira et al., 2022; Percoco, 2010; Pompili et al., 2019). In other words, the impact of digital technologies can vary considerably depending on the museum's location. In urban areas with robust transportation networks, museums can effectively use these technologies to improve visitors' experience. By contrast, in more isolated locations, where accessibility issues can potentially discourage visitors, the implementation of digital tools is essential. In the latter case, digital innovations can in fact be decisive in increasing the number of visits, by making the on-site experience more attractive with significant economic benefits.

3 Conceptual framework

As emerges from the literature review, the impact of digital technologies on the economic performance of museums operates through multiple channels, which we explicitly outline in our conceptual framework.

We distinguish between *digital supports*, which directly improve the quality of visitors' experiences on-site and *web services*, which primarily improve remote accessibility, visibility and transactions (Cavaliere et al., 2024).

Specifically, we consider the following categories of digital media: (1) Smartphone and tablet applications, (2) Interactive configurations, (3) QR codes and proximity systems, (4) Publicly available tablets, (5) Free Wi-Fi connection. *Smartphone and tablet apps* provide interactive and personalized content, increasing visitor engage-

ment and potentially encouraging longer stays (Laudazi & Boccaccini, 2014). *Interactive configurations*, such as touchscreens and virtual reality, transform exhibitions into immersive learning environments, leading to greater satisfaction and eventually repeat visits (Pattakos et al., 2023). *QR codes and proximity systems* allow immediate access to multimedia content, enriching visitors' understanding and prolonging the time spent in the museum (Pérez-Sanagustín et al., 2016). *Public tablets* engage users with interactive features, increasing educational value and satisfaction (Grone-mann, 2017). Finally, *free Wi-Fi* supports wider access to digital services and social sharing, improving visibility and supporting revenue through increased promotional opportunities.

In contrast, online digital services, include: (1) Online ticketing platforms, (2) Social media accounts, (3) Virtual tours, (4) Digital catalogs. *Online ticketing* simplifies the visitor access process, reduce entry barriers and enable dynamic pricing models, thus increasing revenue through improved accessibility (Guccio et al., 2023). *Social media accounts* play a crucial role in marketing, extending global visibility and engaging a wider audience, which leads to increased visitation rates and a greater market reach (Padilla-Meléndez & del Águila-Obra, 2013). *Virtual tours* offer remote access to exhibitions, attracting visitors who are unable to physically visit the site and providing additional revenue opportunities through premium content (Resta et al., 2021). *Digital catalogs* enrich the visitor experience by providing in-depth information and interactive content accessible from anywhere, which increases educational value and encourages upselling of related products or services (Beene et al., 2020).

To correctly assess the relationship between the adoption of digital technologies and museums' economic performance, our model integrates a detailed set of *control variables* that relate to both institution's characteristics (governance, initiatives, marketing and other museum-specific features¹) and local context factors (economic conditions, tourist flows and transport infrastructure). These controls are essential to isolate the effects of digital media and web services from that of other potential confounding factors.

The museum's *governance structure* significantly influences its economic performance through various channels (Bertacchini et al., 2018). The *ownership*, whether public or private, influences funding sources and strategic priorities. Public museums often rely on government subsidies and have cultural preservation as their main goal, while private museums rely more on donations and revenue from visitors, pushing them towards more visitor-centric offers. *Management*, whether direct by the owners or indirect through external operators, also affects operational efficiency and decision-making (Di Liddo et al., 2023). Direct management ensures that strategic objectives are more aligned with the owners' vision, potentially leading to more consistent branding and a better visitor experience. By contrast, external operators can bring in specialized skills and efficiency, but may prioritize profitability, sometimes

¹ These include for instance the main type of institution according to the following classification: (1) Art (up to the 19th century), (2) Modern and contemporary art, (3) Religion, (4) Archaeology, (5) History, (6) Natural history and natural sciences, (7) Science and technology, (8) Ethnography and anthropology, (9) Thematic, (10) Industrial, (11) House of memory. Indeed, as a referee pointed out, some types of museums tend to be more innovative than others and this could influence the effect of technology adoption on economic performance.

to the detriment of educational or cultural objectives. Furthermore, *financial strategies*, which include public funding, private investment and revenue from ancillary services, shape the financial operations of museums (Romolini et al., 2020). These revenue streams can subsidize ticket prices, making museums more accessible, or fund special exhibitions and digital initiatives, improving visitor experience and operational sustainability. Finally, a museum's affiliation with a *network* allows it to take advantage of shared resources and joint initiatives, expanding its reach and operational capabilities. Networks facilitate knowledge sharing and the diffusion of innovation, which are essential to remain relevant in a constantly evolving cultural sector (Scrofani & Ruggiero, 2013).

In addition to governance, our model takes into account of a wide range of *initiatives and strategies* in order to control for their potential influence on the relationship between the use of digital technologies and economic performance. Indeed, activities and marketing are crucial for enhancing visitor engagement. *Activities* such as themed courses, educational workshops and guided tours not only enrich the visitor experience, but also meet the diverse needs of the public, fostering a deeper connection with the community (Yoo, 2021). The organization of conferences and seminars establishes the museum as a hub of knowledge, while live performances and temporary exhibitions attract a wider audience, increasing the number of visits and public interest. *Partnerships* are crucial for the optimization of resources and the expansion of the audience. Collaborating with other cultural institutions generates synergistic effects, such as shared marketing activities, combined ticketing systems or co-hosted events, which improve visibility and accessibility. These alliances allow museums to offer a more complete experience, attractive to both local customers and tourists (Gupta et al., 2010). *Communication campaigns* are customized to meet the interests of specific groups. By developing targeted marketing strategies, museums can effectively communicate their offerings, ensuring inclusivity and accessibility. Therefore, targeted campaigns not only help to create a diverse audience, but also demonstrate museum's commitment to the educational and cultural enrichment of all segments of the community (French & Runyard, 2011).

Finally, our model also considers the *local external factors* that have been identified by the literature as relevant for a museum's success. These include municipality characteristics such as the presence of tourists, which increases the demand for cultural services (Petrei et al., 2020); the average income of citizens, which affects the purchasing power of local visitors (Håkonsen & Løyland, 2016); and local spending on cultural goods, which reflects the community's investment in cultural heritage (Getzner, 2022). In addition, the availability of infrastructure, i.e. the proximity to transportation hubs such as railways and airports, is crucial as it directly affects visitor accessibility (Campa et al., 2019). Well-connected museums often have higher attendance rates, as convenient access is key to attracting both tourists and local visitors. As a result, museums in remote areas could greatly benefit from exploiting digital technologies to improve both their accessibility and attractiveness (Mansour et al., 2022). Indeed, by taking advantage of virtual tours, social media and digital catalogs, these institutions can transcend geographical boundaries, attracting a global audience and expanding their educational reach.

We measure the correlation of digital technologies with three key metrics of *economic performance*: (1) Total visits, (2) Paid visits and (3) Revenue. These variables serve as indicators for broader engagement activities, reflecting the immediate benefits of improved digital interaction and accessibility facilitated by ICTs (Fernandez-Blanco & Prieto-Rodriguez, 2020; Frey & Meier, 2006; Johnson & Thomas, 1991; Romolini et al., 2020; Tohmo, 2004). The *total number of visits* reflects the overall museum attendance and is considered an indicator of general public interest and institution’s appeal, which is often amplified by effective digital strategies. *Paid visits* refer to the subset of total visits in which visitors contribute financially through entrance tickets, playing a direct role in revenue generation. Finally, *revenue* from ticket sales captures the financial returns from admissions and can be positively affected by digital engagement, which helps attract larger paying audiences by stimulating interest in on-site experiences. Our conceptual framework is summarized in Fig. 1.

This framework sets the stage for our *empirical analysis*. The aim is to measure how the adoption of digital technologies improves visitors’ experience and accessibility and to determine how these improvements translate into tangible economic benefits. In addition, drawing on the literature that emphasizes the uneven impact of digital technologies on economic outcomes and the importance of institutional and local contexts, we examine how these dynamics are shaped by the governance structures and infrastructural conditions in which they are embedded. These insights inform our hypotheses, indicated by the letter “H” followed by a sequential number and shape the direction of our investigation:

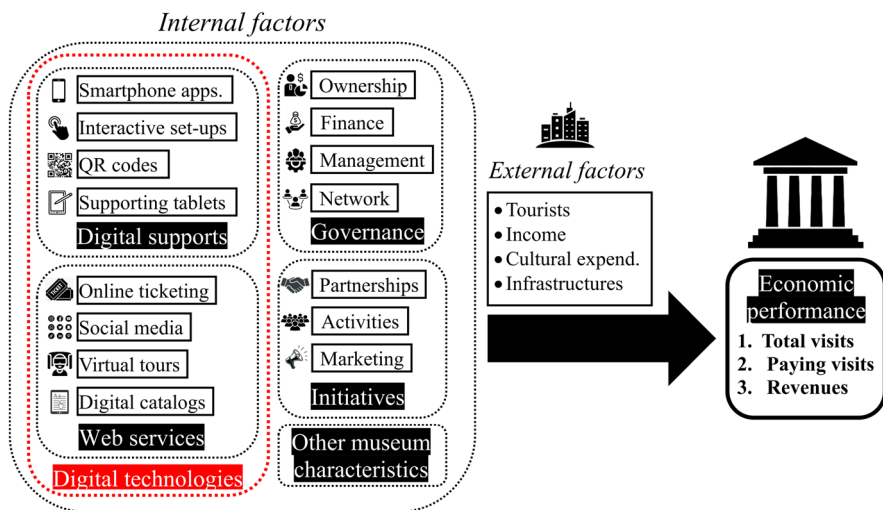


Fig. 1 Digital technologies and economic performance of museums. We capture the relationship between the adoption of *digital technologies* (digital media and web services) and the *economic performance* of museums. To remove any confounding factors, we control for governance, initiatives and other museum-specific characteristics, as well as for local external factors at the municipal-level. Source: Authors’ own elaboration

H1 *The adoption of digital supports is positively associated with museum attendance, although the magnitude of this relationship is expected to vary across different types of technologies.*

H2 *The adoption of web services is positively associated with museums' revenue, although the magnitude of this relationship is expected to vary across different types of services implemented.*

H3 *The relationship between ICT adoption and museums' economic performance is shaped by institutional and local contextual factors, including management type, ownership structure and infrastructure accessibility.*

4 Empirical analysis

4.1 Data description

The empirical analysis uses data from the Italian survey of museums and similar institutions (*Indagine sui musei e le istituzioni similari*), conducted by the Italian Statistical Office (ISTAT). This survey has been carried out periodically since 2011, covering museums, galleries, collections, archaeological parks and areas, monuments and monumental complexes. It collects comprehensive information on institutional characteristics, including the type and scale of collections, ownership, management, financial structure, cultural activities, communication strategies and the integration of digital technologies.²

The 2018 wave of the survey includes data from 4,903 institutions, while the 2022 wave includes 4,416 respondent units. Given the predominance of museums in the sample (79% in 2018 and 77% in 2022) and their specific characteristics in terms of management, conservation and technology adoption, we focus specifically on this latter category.³ Observations with incomplete information relating to key independent variables were removed, resulting in a final sample of 1,858 museums that we observe in both years (the complete list of variables with their description and matching in the two years is given in Tables A1–A3). This dataset is further integrated with municipal-level information from ISTAT, the Ministry of Economy and Finance (MEF) and the State General Accounting Department (RGS), which include local economic, tourist and infrastructural characteristics (see Table A4). These external variables, including municipal spending on cultural heritage (Dalle Nogare & Galizzi, 2011) and proximity to transport infrastructure (Campa et al.,

²The survey on museums and similar institutions is carried out by ISTAT, the Ministry of Cultural Heritage, Activities and Tourism (MiBACT), Italian Regions and Autonomous Provinces. Microdata and a detailed methodological note are available at: <https://www.istat.it/microdati/indagine-sui-musei-e-le-istituzioni-similari>. The survey has been conducted in 2011, 2015 and annually from 2017 to 2022. The waves used in this study are those from 2018 and 2022. See Appendix A.1 for methodological details.

³Estimates for the entire sample, which includes also archaeological parks and monumental complexes, are available upon request to the authors.

2019), have been recognized by the literature as crucial determinants of museums' economic performance.

Table 1 summarizes the geographical distribution and the main characteristics of the Italian museums included in our sample in 2022.

It is worth noting that museums are distributed throughout Italy, with a greater concentration in the northern (47%) and central (31%) regions, compared to the South (23%). Tuscany has the highest number of institutions (244), followed by Emilia-Romagna (197), Lombardy (197), Piedmont (158) and Lazio (149).

Panel (a) provides a breakdown by *main typology*. It shows that archaeology (19%), traditional art (up to the 19th century) (16%), thematic and specialized museums (13%), ethnographic and anthropological museums (11%) and modern and contemporary art (10%) museums are the prevailing categories.

Table 1 Main features of museums in the dataset (2022)

Panel (a) - Breakdown by museum typology

Geographic area	Italy		North		Center		South	
	Total	%	Total	%	Total	%	Total	%
Art (up to 19th century)	294	16%	121	14%	121	21%	52	12%
Modern and contemporary art	194	10%	82	9%	68	12%	44	10%
Religion and worship	80	4%	31	4%	19	3%	30	7%
Archaeology	354	19%	105	12%	128	23%	121	28%
History	147	8%	96	11%	33	6%	18	4%
Natural history	148	8%	76	9%	37	7%	35	8%
Science and technology	50	3%	25	3%	17	3%	8	2%
Ethnography/anthropology	212	11%	113	13%	42	7%	57	13%
Thematic and specialized	241	13%	136	16%	68	12%	37	9%
Industrial and business	37	2%	22	3%	10	2%	5	1%
House museum	70	4%	37	4%	18	3%	15	4%
Other typology	31	2%	20	2%	6	1%	5	1%
<i>Total</i>	<i>1858</i>	<i>100%</i>	<i>864</i>	<i>100%</i>	<i>567</i>	<i>100%</i>	<i>427</i>	<i>100%</i>

Panel (b) - Visits, paid visits and revenue

Geographic area	Italy		North		Center		South	
	Total	%	Total	%	Total	%	Total	%
Opening and entrance								
Opening days per week (mean)	4.96		4.42		4.96		5.49	
Free entrance	706	38%	355	19%	184	10%	167	9%
Visits (total)	32,487,587		16,800,000		10,100,000		5,587,587	
Visits (median)	2912		3,088		2,874		2775	
% of Italians	78%		82%		76%		77%	
% of Foreigners	22%		18%		24%		23%	
Paid visits (total)	20,505,278		10,600,000		6,458,692		3,446,586	
Paid visits (median)	2357		3000		2020		2050	
Revenue								
Revenue (0–10,000€)	606	33%	247	41%	205	25%	154	36%
Revenue (10,000€- 100,000€)	373	20%	115	19%	175	21%	83	19%
Revenue (>100,000€)	879	47%	247	41%	442	54%	190	44%
<i>Total</i>	<i>1858</i>	<i>100%</i>	<i>609</i>	<i>100%</i>	<i>822</i>	<i>100%</i>	<i>427</i>	<i>100%</i>

Other typology refers to museums with mixed collections, e.g. city museums

Panel (b) shows data on visits, together with revenue and some operational indicators. Starting from the latter, we observe that Italian museums are usually open about five days a week, which is in line with standard working hours in the country.⁴ Furthermore, 706 institutions (38%) offer free admission, underlining the importance of accessibility and community involvement (O'Hare, 1975).

Data on visits indicate a total of about 32.5 million visits, mainly from national visitors (78%), while international visitors still represent a considerable minority (22%). The foreign presence is higher in the central and southern regions (23–24%) than in the north (18%), reflecting the greater international appeal of the cultural sites in these regions.

Financially, there is substantial variability among Italian museums: while nearly half of the sample (47%) achieves revenue from ticket sales exceeding 100,000€, about one-third (33%) reported minimal revenue below 10,000€. Museums receiving the highest number of visits and the greatest revenue are predominantly located in central Italy, underscoring the region's strong cultural appeal and the presence of important, internationally recognized institutions.⁵ The average number of paid visits compared to the total number of visits highlights significant differences between museums in different regions. Museums in the north have a higher percentage of paid visits (3,000 out of 3,088, or 97.1%) than those in the central regions (2,020 out of 2,874, or 70.3%) and in the south (2,050 out of 2,775, or 73.9%). This picture highlights financial disparities and different institutions' abilities to attract and retain a paying audience, in line with previous research indicating that these differences stem from geographical location, museum typology, visitor engagement strategies and operational practices (Agostino, 2024; Alfano et al., 2023; Bertacchini et al., 2018; Cellini et al., 2018, 2020; Navarrete, 2020; Trupiano, 2005).

In Table 2 we show a breakdown of the *governance* and *initiative* variables. These emphasize museums' operational strategies and public engagement efforts.

The *governance* section (Panel a) highlights the predominance of public ownership, with 70% of Italian museums being publicly owned. This suggests a strong role for government in the museum sector, reflecting a public commitment to cultural preservation and accessibility. Furthermore, 26% of the institutions employ management structures that are separate from the ownership, indicating a preference for operations involving outsourced management services. This model allows for flexibility and expertise from external organizations, although it also introduces more complexity in ensuring alignment of objectives and quality control. The funding sources are diverse, reflecting the diversified approaches adopted by Italian museums

⁴This five-day average is purely descriptive and should not be interpreted as adherence to standard office-hour schedules. Italian museums typically close on a low-attendance weekday and remain open on weekends and public holidays, when visitor demand peaks (Jalla, 2025). The dataset does not contain detailed information on daily or hourly opening times.

⁵In 2022, the Italian museums in our dataset with the highest number of visits were: (1) Galleria degli Uffizi - 2,222,692; (2) Galleria dell' Accademia - 1,428,369; (3) Palazzo Ducale di Venezia - 1,118,443; (4) Museo Egizio - 907,364; (5) Reggia di Caserta - 760,807; (6) La Triennale di Milano - 661,234; (7) Palazzo Pitti - 650,612; (8) National Cinema Museum - 567,180; (9) Sansevero Chapel Museum - 558,895; (10) Galleria Borghese - 544,290. These institutions are mainly located in central and southern Italy.

Table 2 Museum governance and initiatives (2022)

Panel (a): Museum governance

Variable	No		Yes		Tot.
	N	%	N	%	
1. Ownership					
Public ownership	564	30%	1294	70%	1858
Private ownership	1294	70%	564	30%	1858
2. Management					
Direct management	482	26%	1,376	74%	1858
Indirect management	1376	74%	482	26%	1858
3. Finance					
Public funding and grants	726	39%	1132	61%	1858
Private funding	1183	64%	675	36%	1858
Other income from additional services	948	51%	910	49%	1858
4. Networks					
Integrated cultural systems	888	48%	970	52%	1858

Panel (b): Museum initiatives

Variable	No		Yes		Tot.
	N	%	N	%	
1. Activities					
Thematic courses for children	692	37%	1166	63%	1858
Educational workshops	685	37%	1173	63%	1858
Guided tours	102	5%	1756	95%	1858
Conventions, conferences and seminars	636	34%	1222	66%	1858
Live performances	815	44%	1043	56%	1858
Exhibitions or temporary exhibitions	690	37%	1168	63%	1858
Room for teaching, study, research activities	542	29%	1316	71%	1858
Video/multimedia room	918	49%	940	51%	1858
2. Partnerships					
Partnerships with other institutions	575	31%	1283	69%	1858
3. Communication					
Campaigns targeting children	726	39%	1132	61%	1858
Campaigns targeting students	633	34%	1225	66%	1858
Campaigns targeting the elderly	1338	72%	520	28%	1858
Campaigns targeting foreigners	1509	81%	349	19%	1858
Campaigns targeting people with disabilities	1308	70%	550	30%	1858

The Governance section outlines museum's operational framework, detailing ownership, management, financial support and network involvement

The Initiatives section captures the extent of visitor engagement through activities, partnerships and communication efforts

See Tables A1-A2 for the complete list of variables and their descriptions

to ensure their financial sustainability. Direct public funding represents the predominant source at 61%, which aligns with the high percentage of publicly owned institutions.⁶ Self-generated income, which includes earnings from bookstores, cafeterias and tourist services, accounts for 49%, demonstrating museums' efforts to leverage

⁶As a referee pointed out, here we refer to direct public funding. In addition to this, Italian museums also receive indirect support through various forms of tax exemptions (Hemels & Goto, 2017).

their resources and visitor services to generate revenue. Private funding contributes 36%, reflecting the important role of donations and sponsorships in supporting the activities of both public and private museums.

From the section dedicated to *museum initiatives* (Panel b), a strong emphasis on public engagement and educational dissemination emerges. Roughly 95% of museums offer guided tours, demonstrating their commitment to improving the visitor experience and educational value. Educational workshops, available in 63% of museums, play a crucial role in involving local communities and promoting a deeper connection with cultural heritage. Partnerships with other cultural institutions, observed in 69% of cases, help to broaden the scope and impact of museum programs, potentially creating synergistic effects that benefit all parties involved. Communication strategies are customized to reach specific demographic groups, reflecting a targeted approach to increase inclusivity and engagement. In this perspective, significant attention is paid to students (66%) and children (61%), with the aim of cultivating an early interest and appreciation for culture that may have a lasting impact on the future development of the audience. There are also notable efforts to accommodate people with disabilities (30%), although this lower percentage suggests that there is still room for improvement in making museums more accessible to all visitors.

Moving on to our independent variable of interest, *digital technologies*, the data presented in Table 3 clearly highlights significant developments in the period 2018–2022, which vary considerably between different types of *physical digital media* (Panel a) and *web-based services* (Panel b).

Starting with Panel (a), the data indicates moderate but noteworthy increases in the adoption of *physical digital media* within Italian museums. In particular, QR codes and proximity systems show the most substantial growth, increasing by 78% from 393 to 699 between 2018 and 2022. This trend highlights the strategic focus of muse-

Table 3 Change in the use of digital technologies (2018–2022)

Panel (a): Digital supports						
Variable	2018		2022		Diff.	
	N	%	N	%	$\Delta N.$	$\Delta(\%)$
Smartphone and tablet applications	299	16%	449	24%	+150	50%
Interactive set-ups	655	35%	852	46%	+197	30%
QR codes and proximity systems	393	21%	699	38%	+306	78%
Tablets available to the public	198	11%	218	12%	+20	10%
Free Wi-Fi connection	634	34%	885	48%	+251	40%
Panel (b): Web services						
Variable	2018		2022		Diff.	
	N	%	N	%	$\Delta N.$	$\Delta(\%)$
Online ticketing service	340	18%	483	26%	+143	42%
Social media accounts	1260	68%	1491	80%	+231	18%
Online virtual tours	253	14%	419	23%	+166	66%
Digital catalogs	304	16%	644	35%	+340	112%

Number (*N*) and share (%) of museums using a given digital technology in 2018 and 2022, based on the total sample of 1858 museums

The *Diff.* column shows the absolute change in number and the relative change compared to 2018 ($\Delta(\%) = (N_{2022} - N_{2018})/N_{2018}$). See Tables A1–A2 for the complete list of variables and their descriptions

ums on improving visitor interactions through personal devices, facilitating access to multimedia and contextual information without physical contact, which has accelerated during the COVID-19 pandemic. Similarly, there has been a notable increase in the availability of smartphone and tablet applications (50%), which suggests a growing emphasis on personalized and interactive visitor experiences. Interactive setups (30%) and free Wi-Fi (40%) also register moderate growth, emphasizing a steady but cautious commitment to improving technological infrastructures. In contrast, the minimal 10% increase in tablets available to visitors implies persistent barriers, perhaps due to high upfront costs, ongoing maintenance expenses, or operational complexities associated with managing physical devices.

Moving to Panel (b), *web-based services* show an even more sustained growth trajectory. Digital catalogs have seen an exceptional increase of 112%, growing from 304 to 644 museums. This exceptional growth rate illustrates museums' commitment to expanding their global reach by improving accessibility and providing rich, searchable digital content, thus improving audience engagement. Furthermore, the significant 66% increase in online virtual tours is in line with broader digital transformation trends intensified by pandemic-related closures, reinforcing the shift of museums towards remote visitor engagement strategies. Similarly, online ticketing services show a substantial rise (42%), reflecting museums' efforts to simplify visitor management and improve accessibility. Finally, social media accounts increased by 18%, reaching 80% overall, underlining the growing recognition of social platforms as vital tools for audience engagement and marketing strategies.

Figure 2 illustrates trends in visits and revenue during the same period.

Panel (a) highlights a substantial increase in total visits, with smaller museums, those attracting fewer than 500 visits annually, experiencing the most notable growth. Panel (b) shows a corresponding rise in the number of paid visits for this category of museums. Finally, Panel (c) illustrates that reported revenue increased alongside these higher visit numbers.⁷ This parallel rise in attendance and revenue reflects museums' capacity to attract paying audiences. However, since revenue is reported in brackets and cannot be deflated, possibly also reflecting higher operating costs, the figures should be viewed as descriptive evidence of co-movement rather than improved economic performance.

4.2 Cross-section

We employ cross-sectional regression analysis to empirically assess the correlations postulated in our conceptual framework. Specifically, we estimate the following linear regression model (OLS):

$$\log(y_i) = \beta'_A A_i + \beta'_B B_i + \beta'_C C_i + \gamma' D_i + \varepsilon_i \quad (1)$$

where $\log(y_i)$ represents the natural logarithm of economic performance metrics for museum i . The specific outcomes examined are: (1) total visits, (2) paid vis-

⁷This includes revenue from season tickets and any other form of access, regardless of where they are issued, as well as tickets issued for any temporary exhibitions and/or other events.

Fig. 2 Distribution of total visits, paid visits and ticket revenue (2018–2022). Bars for 2018 (green) and 2022 (grey) are shown side by side. The y-axis reports the number of museums in each class; x-axis classes replicate ISTAT survey brackets. Revenue refers to admission revenue in nominal euros and is interval-censored. Sample restricted to museums observed in both years. Source: Authors' calculations from ISTAT microdata



its and (3) institutional revenue.⁸ For revenue, which are interval-censored in the original dataset, we apply interval regression methods (Long, 1997; Long & Freese, 2006; Stewart, 1983; Tobin, 1958), ensuring coefficient interpretability analogous to standard OLS. The independent variables capture distinct factors affecting museum performance⁹:

- *Digital technologies* (A_i): is a vector measuring the effect of digital technology adoption, explicitly distinguishing between *digital supports* and *web services*, in line with our conceptual distinctions;
- *Institution-level controls* (B_i): is a vector containing specific controls for all *museum characteristics* that can influence the relationship between digital technologies and economic performance (these include governance, operational features, financial sources and visitor engagement initiatives);
- *Municipality-level controls* (C_i): is a vector including controls for *external context factors*, including local economic conditions, tourist attractiveness, investments in cultural heritage and infrastructural accessibility.

The term $\gamma' D_i$ represents categorical variables: *type of museum* (i.e. art, history, science, etc.); *ownership entity* (i.e. the MiBACT, ecclesiastical organization, private company, etc.) and Italian regions (i.e. Abruzzo, Basilicata, Calabria, etc.). Each categorical variable is transformed into a set of dummies (= 1 if observation i belongs to the group, = 0 otherwise). Therefore, the vector γ includes coefficients that measure the average effect of each category, compared to a reference group. Finally, ϵ_i is the error or residual term.

Table 4 presents the cross-sectional results, showing how differences in ICT adoption across museums in 2022 are associated with differences in their performance. The estimates thus capture systematic *between-museum* differences rather than changes over time.

Starting with *digital supports*, the presence of interactive video and touchscreens shows a consistent and statistically significant positive association with total visits (coefficients around 0.23, $p < 0.01$), paid visits (0.21, $p < 0.05$) and revenue (0.36, $p < 0.01$), suggesting that museums equipped with interactive on-site technologies tend to attract more visitors and generate higher revenue. This aligns with previous evidence highlighting the role of interactive tools in enhancing engagement and satisfaction (Pallud, 2017). QR codes also correlate positively with total visits (0.18–0.19, significant at $p < 0.05$ and $p < 0.01$), acting as complementary rather than pri-

⁸A referee noted that revenue in the panel analysis could be affected by inflation. Since revenue is recorded as interval categories rather than continuous monetary values (with the unobserved y_i falling within the interval $[y_{1j}, y_{2j}]$), it is not possible to directly deflate the data. However, we account for inflation, approximately 9% cumulatively between 2018 and 2022 according to Eurostat, by interpreting category shifts conservatively and acknowledging this limitation. As an additional robustness check, we re-estimated the models using broader revenue groupings to assess whether small bracket shifts, potentially attributable to inflation alone, could affect our results. The findings remain consistent across alternative specifications.

⁹The vectors β_A , β_B and β_C contain the coefficients that capture the effects of the variables in A_i , B_i and C_i , respectively, on $\log(y_i)$, holding other factors constant.

Table 4 Effects of digital technologies on museum performance: Cross-sectional regression results (2022)

Variable	Total visits		Paid visits		Revenue	
	(1)	(2)	(1)	(2)	(1)	(2)
	Digital supports					
Smartphone and tablet apps	0.02 (0.08)	0.02 (0.08)	0.01 (0.12)	-0.01 (0.13)	0.14 (0.16)	0.16 (0.20)
Video and touchscreens	0.23*** (0.06)	0.23*** (0.07)	0.21** (0.09)	0.21** (0.11)	0.36*** (0.14)	0.19 (0.18)
QR codes and proximity systems	0.19*** (0.07)	0.18** (0.08)	0.13 (0.11)	0.10 (0.11)	0.06 (0.16)	0.06 (0.17)
Publicly available tablets	-0.06 (0.09)	-0.04 (0.09)	-0.10 (0.13)	-0.14 (0.14)	-0.07 (0.18)	-0.23 (0.21)
Free Wi-Fi connection	-0.12* (0.07)	-0.10 (0.07)	-0.06 (0.09)	-0.07 (0.10)	0.10 (0.14)	0.01 (0.15)
	Web services					
Online ticketing service	0.87*** (0.07)	0.74*** (0.08)	0.94*** (0.10)	0.84*** (0.11)	1.13*** (0.15)	1.01** (0.50)
Social media accounts	0.08 (0.09)	0.10 (0.11)	0.17 (0.17)	0.17 (0.19)	0.40 (0.26)	0.53 (0.36)
Online virtual tours	0.13* (0.07)	0.04 (0.08)	0.17 (0.11)	0.08 (0.11)	-0.04 (0.17)	-0.19 (0.22)
Digital catalogs	-0.03 (0.07)	-0.06 (0.07)	-0.13 (0.10)	-0.09 (0.11)	-0.08 (0.15)	0.03 (0.16)
Tip/own/reg. dummies	YES	YES	YES	YES	YES	YES
Municipal-level controls	NO	YES	NO	YES	NO	YES
Number of observations	1,858	1,402	1,150	896	1,147	894
r^2	0.56	0.58	0.53	0.57	/	/
Log-likelihood	-2,955.70	-2,147.20	-1984.80	-1,494.80	-2,317.90	-1,797.60

Columns (1)–(4) report OLS estimates; columns (5)–(6) report interval regression coefficients

Robust standard errors are shown in parentheses

Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All specifications include dummies for museum type, ownership and region. Specifications (2), (4), and (6) additionally control for municipal characteristics and accessibility indicators

Further controls, included in all models, comprise museum opening hours, visitor composition, partnerships, network participation, service offerings, financing sources and communication

See Tables A1–A2 for the full list

mary drivers of visitor inflows (Schultz, 2013). In contrast, public tablets and Wi-Fi connections show no significant relationship with attendance or revenue, echoing earlier findings on the limited economic value of general connectivity amenities (Lambert et al., 2014).

Turning to *web services*, online ticketing systems emerge as the strongest correlate of better performance, positively associated with total visits (0.74–0.87, $p < 0.01$), paid visits (0.84–0.94, $p < 0.01$) and revenue (1.01–1.14, $p < 0.05$ and $p < 0.01$), underscoring the role of digital sales channels in improving accessibility and monetization (Charitonos et al., 2012). By contrast, social media accounts and digital

catalogs show no significant association, while the weak positive link between virtual tours and total visits ($p < 0.1$) disappears once municipal-level controls are added (Padilla-Meléndez & del Águila-Obra, 2013). Overall, the results suggest that, *across museums*, those adopting interactive on-site technologies and online ticketing systems systematically perform better, whereas other digital tools appear less relevant or context-dependent.

4.3 Panel

To capture both cross-sectional and temporal dimensions of museum performance, we extend the analysis by exploiting the panel structure of the data. We match two harmonized waves of the ISTAT survey on Italian museums, namely 2018 and 2022.¹⁰ This panel structure allows us to account for both systematic differences across museums and within-museum changes over time. We estimate the following specification:

$$\log(y_{it}) = \beta'_A A_{it} + \beta'_B B_{it} + \beta'_C C_{it} + \gamma' D_{it} + u_i + \varepsilon_{it}, \quad (2)$$

for $i \in \{1, \dots, N\}$, $t \in \{2018, 2022\}$.

The vectors A_{it} , B_{it} and C_{it} are defined as in the cross-sectional setting and capture, respectively: (i) adoption of digital technologies, (ii) museum-level characteristics (governance, management practices, initiatives, financing), and (iii) the municipal context (local economic conditions, tourism, accessibility). The vector D_{it} includes categorical attributes such as museum typology, ownership and region. The term u_i absorbs all unobserved, time-invariant, museum-specific factors (e.g. collection quality, long-run reputation, persistent managerial capability), while ε_{it} is the idiosyncratic error. Because revenues are reported in intervals in the survey, revenue models are estimated via interval regression, whereas visit models are estimated using linear specifications.

A key issue in this setting is unobserved heterogeneity. A standard random effects (RE) estimator would require u_i to be uncorrelated with the observed regressors, which is unlikely here: museums with higher-prestige collections or stronger management may both be more likely to adopt digital technologies and systematically attract more visitors. At the same time, a conventional fixed-effects (FE) estimator is not attractive. With only two periods ($T = 2$), within-museum variation is mechanically limited, and for the interval-censored revenue outcome a nonlinear FE estimator would suffer from the incidental parameters problem in short panels (Baltagi, 2010; Greene, 2001, 2004; Lancaster, 2000; Moreira, 2008; Neyman & Scott, 1948; Wooldridge, 2010).

We therefore adopt a correlated random effects (Mundlak-Chamberlain) specification (Chamberlain, 1982; Mundlak, 1978; Wooldridge, 2010). Concretely, for each time-varying regressor we include its museum-specific average over time in the model. This relaxes the strict RE independence assumption by allowing u_i to be correlated with the regressors through these museum-level means. Intuitively, this

¹⁰ Although the ISTAT survey covers multiple years, full harmonization of the variables used in this analysis is only possible for these two waves. See Table A3 for more details.

approach differences out the influence of stable, unobserved traits such as collection prestige, established brand, or managerial quality, traits that are plausibly linked to both ICT adoption and performance, while retaining the efficiency and feasibility of a RE framework in a short panel. All specifications include region dummies and a year dummy to absorb spatial and common time shocks, and standard errors are clustered at the museum level.

Under this formulation, the coefficients on the time-varying regressors can be interpreted as capturing the association between within-museum changes in digital technologies and changes in performance between 2018 and 2022, net of time-invariant unobservables. At the same time, because we also condition on the museum-specific means (the Mundlak terms), the model still reflect systematic between-museum differences in digital intensity and performance.

Table 5 reports the main correlated RE estimates for 2018–2022. In this specification, total visits, paid visits and reported revenue bounds are winsorized at the 1st and 99th percentiles prior to log transformation.¹¹ The full set of coefficient estimates, including the Mundlak terms, together with robustness checks (non-winsorized outcomes and samples excluding the upper 5% and 10% of museums), is reported in Appendix A.2 (Tables A5–A8).

The *between* r^2 values (0.50–0.60) are much larger than the *within* r^2 values (0.05–0.17), indicating that most of the explanatory power comes from systematic differences *across* museums rather than short-run changes *within* the same museum between 2018 and 2022. This is expected in a short panel, where within-museum variation is mechanically limited. Importantly, however, the correlated REs specification means these “between-museum” patterns are not just raw cross-sectional correlations: by adding museum-level means of the time-varying regressors, we soak up time-invariant traits such as prestige, location appeal or managerial quality. The coefficients should therefore be read as describing how (partly persistent) differences in digital adoption relate to performance, net of those stable unobservables, rather than as pure before/after effects.

Among *physical digital supports*, smartphone and tablet applications are positively associated with total visits (0.09, $p < 0.1$) and paid visits (0.17, $p < 0.1$; 0.22, $p < 0.05$), but not clearly with revenue. Interactive videos and touchscreens show a stronger and more consistent association: they are linked to higher total visits (0.12, 1–5% significance) and higher paid visits (0.18, 1–5% significance), suggesting that museums with immersive on-site experiences tend to attract and convert more visitors. QR codes and proximity systems have no systematic effects on attendance or revenue; free Wi-Fi is essentially neutral, consistent with it being a baseline amenity; and publicly available tablets are weakly negatively associated with paid visits (-0.27 , $p < 0.1$), possibly reflecting heterogeneity across museums, as such devices are more common in smaller or less resource-intensive institutions (Gronemann, 2017).

¹¹As noted by a referee, museum attendance and revenue are highly skewed, with a few large “blockbuster” museums generating most visits and income. To mitigate their potential influence, we winsorize extreme values at the 1st and 99th percentiles, thereby limiting the leverage of outliers while preserving the representativeness of the sample.

Table 5 Time-varying effects of digital technologies: Panel analysis with Mundlak means (2018-2022)

Variable	Total visits		Paid visits		Revenue	
	(1)	(2)	(1)	(2)	(1)	(2)
	Digital supports					
Smartphone and tablet apps	0.06 (0.05)	0.09* (0.05)	0.17* (0.09)	0.22** (0.10)	0.12 (0.12)	0.08 (0.14)
Video and touchscreens	0.12*** (0.04)	0.12** (0.05)	0.18*** (0.07)	0.18** (0.08)	0.17 (0.11)	0.15 (0.13)
QR codes and proximity systems	0.05 (0.04)	0.03 (0.05)	0.05 (0.08)	0.01 (0.09)	0.02 (0.11)	0.07 (0.12)
Publicly available tablets	-0.02 (0.06)	-0.10 (0.07)	-0.16 (0.12)	-0.27* (0.15)	0.02 (0.15)	-0.05 (0.17)
Free Wi-Fi connection	0.00 (0.04)	0.03 (0.05)	0.07 (0.07)	0.10 (0.08)	0.08 (0.11)	0.03 (0.13)
	Web services					
Online ticketing service	0.11** (0.05)	0.14** (0.05)	0.19** (0.08)	0.13 (0.10)	0.34*** (0.11)	0.37*** (0.14)
Social media accounts	0.03 (0.06)	0.00 (0.07)	0.11 (0.12)	-0.06 (0.13)	0.20 (0.16)	0.29 (0.19)
Online virtual tours	0.04 (0.04)	-0.02 (0.05)	-0.09 (0.06)	-0.14* (0.07)	-0.21* (0.12)	-0.33** (0.14)
Digital catalogs	-0.01 (0.04)	0.00 (0.05)	-0.04 (0.09)	0.06 (0.10)	0.14 (0.11)	0.12 (0.13)
Typo/own/reg. dummies	YES	YES	YES	YES	YES	YES
Municipal-level controls	NO	YES	NO	YES	NO	YES
Number of observations	3,902	2,907	2,347	1,792	2,335	1,786
Number of groups	2,232	1,744	1,378	1,097	1,371	1,092
r^2 (within)	0.17	0.17	0.05	0.06	/	/
r^2 (between)	0.59	0.60	0.50	0.54	/	/
r^2 (overall)	0.57	0.58	0.49	0.53	/	/
Log-likelihood	/	/	/	/	-4,490.14	-3,485.68

Columns (1)-(4) report random effects (RE) regression coefficients; columns (5)-(6) report RE interval regression coefficients

Robust standard errors clustered by museum are shown in parentheses

Statistical significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

All specifications include museum type, ownership, regional and year fixed effects, as well as Mundlak means (museum-level averages) of all time-varying regressors to account for correlated REs

Dependent variables are winsorized at the 1st and 99th percentiles before log transformation

Specifications (2), (4), and (6) additionally control for municipal characteristics and accessibility indicators

Further controls, included in all models, comprise museum opening hours, visitor composition, partnerships, network participation, service offerings, financing sources and communication

Estimation results with Mundlak means are reported in Table A5

Turning to *web services*, online ticketing stands out. It is positively associated with total visits (0.11–0.14, both $p < 0.05$), paid visits (0.19, $p < 0.05$) and revenue (0.34–0.37, both $p < 0.01$), pointing to a clear commercial role. Social media accounts, by contrast, show no robust association with either visits or revenue once we condition

on museum-specific factors. Online virtual tours are negatively associated with paid visits (-0.14 , $p < 0.10$) and revenue (-0.21 , $p < 0.10$; -0.33 , $p < 0.05$), without affecting total visits, consistent with *partial substitution* away from on-site, ticketed access. Digital catalogs show no systematic link to performance, in line with their primarily curatorial function.

5 Heterogeneity in digitalization effects

The previous section showed that certain classes of digital technologies adopted by Italian museums are systematically associated with stronger performance. We now explore whether these effects differ across institutional settings and local contexts. Specifically, we focus on three sources of *heterogeneity*: ownership (public vs. private), management (direct vs. indirect), and infrastructural accessibility of the hosting municipality (weak vs. strong). Tables 6–8 present the estimated heterogeneous effects of digitalization across these dimensions.

5.1 Ownership

We begin with *ownership* (Table 6), where a divergence emerges between public and private museums in how digital technologies relate to performance.

Public museums benefit most from on-site *digital supports*. Interactive video installations and touchscreens are strongly associated with both higher overall attendance (0.18 , $p < 0.01$) and higher paid attendance (0.26 , $p < 0.01$), suggesting that immersive, didactic media are particularly effective in attracting and engaging visitors in this segment. By contrast, tools such as mobile applications, QR codes, or Wi-Fi access show no systematic link with either visits or revenue, and the presence of online virtual tours is actually associated with lower revenue (-0.28 , $p < 0.1$). Taken together, these patterns are consistent with the institutional mission of public museums, which typically emphasises education, cultural access, and social outreach rather than direct commercial returns. In this setting, investments in on-site experiential technologies seem to reinforce that mission by drawing audiences into the physical space (Federici & Parisi, 2022; Sandell, 2003), whereas purely remote or informational tools do not appear to translate into stronger in-person participation.

Private museums, by contrast, appear to benefit more from *web-based services* than from purely on-site digital installations. Online ticketing is positively associated with both total visits (0.26 , $p < 0.05$) and revenue (0.57 , $p < 0.1$), and digital catalogs are linked to higher numbers of paying visitors (0.33 , $p < 0.1$). This suggests that, in privately managed institutions, digitalisation mainly operates through visibility and access: making it easier for potential visitors to discover the museum, plan a visit, and purchase entry. At the same time, online virtual tours are negatively associated with revenue in both ownership groups, and the effect is markedly stronger for private museums (-0.69 , $p < 0.05$). This is consistent with partial substitution: when high-quality content can be consumed remotely, the incentive to purchase in-person access weakens, especially where sustaining visitor-funded activity is central. Overall, public museums appear to leverage on-site, interactive technologies to

Table 6 Heterogeneity analysis by *museum ownership*: Within-museum effects of digital technologies (2018–2022)

Variable	Public museums			Private museums		
	Tot. visits	Paid visits	Revenue	Tot. visits	Paid visits	Revenue
	Digital supports					
Smartphone and tablet apps	0.04 (0.06)	0.21 (0.13)	−0.01 (0.15)	0.15 (0.11)	0.24 (0.22)	0.03 (0.34)
Video and touchscreens	0.18*** (0.06)	0.26*** (0.08)	0.06 (0.13)	0.03 (0.09)	0.08 (0.20)	0.43 (0.29)
QR codes and proximity systems	0.05 (0.06)	0.07 (0.09)	0.07 (0.13)	0.01 (0.09)	−0.14 (0.19)	0.09 (0.29)
Publicly available tablets	−0.10 (0.07)	−0.38** (0.18)	−0.09 (0.17)	0.00 (0.16)	0.29 (0.31)	0.54 (0.43)
Free Wi-Fi connection	−0.03 (0.06)	−0.06 (0.08)	−0.04 (0.14)	0.14 (0.09)	0.44*** (0.15)	0.17 (0.28)
	Web services					
Online ticketing service	0.05 (0.06)	−0.04 (0.10)	0.20 (0.15)	0.26** (0.12)	0.38 (0.23)	0.57* (0.31)
Social media accounts	0.06 (0.08)	0.03 (0.11)	0.22 (0.20)	−0.17 (0.17)	−0.40 (0.39)	0.31 (0.45)
Online virtual tours	0.04 (0.06)	−0.08 (0.09)	−0.28* (0.15)	−0.12 (0.09)	−0.24 (0.16)	−0.69** (0.31)
Digital catalogs	−0.00 (0.06)	−0.03 (0.13)	0.14 (0.14)	0.05 (0.10)	0.33* (0.18)	0.17 (0.29)
Tipo/own/reg. dummies	YES	YES	YES	YES	YES	YES
Municipal-level controls	YES	YES	YES	YES	YES	YES
Number of observations	1,954	1,207	1,199	953	585	587
Number of groups	1,179	750	745	598	370	372
r^2 (within)	0.21	0.09	/	0.18	0.15	/
r^2 (between)	0.60	0.57	/	0.59	0.59	/
r^2 (overall)	0.59	0.55	/	0.55	0.54	/
Log-likelihood	/	/	−2,212.20	/	/	−1,225.30

Estimates follow the same correlated REs (Mundlak) specifications as Table 5, reported separately for *public* (columns 1–3) and *private* (columns 4–6) museums

Robust standard errors clustered by museum are shown in parentheses

Statistical significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

All models include museum type, ownership, regional and year fixed effects, as well as Mundlak means of time-varying regressors

Dependent variables are winsorized at the 1st and 99th percentiles before log transformation

Estimation results with Mundlak means are reported in Table A9

attract visitors into the building, whereas private museums rely more on outward-facing digital channels that lower barriers to entry and help convert interest into paying attendance (Algieri et al., 2023; Coblenz & Sabatier, 2014).

5.2 Management

The *management structure* (Table 7) introduces another layer of heterogeneity, revealing distinct patterns in how digital technologies translate into performance under direct versus indirect management.

In *directly managed* museums, the adoption of digital tools is systematically associated with stronger outcomes in terms of both attendance and revenue. On-site technologies that support the visitor experience, for example, smartphone and tablet applications, are linked to higher numbers of paying visits (0.23, $p < 0.05$), and free Wi-Fi access shows a similar positive association (0.21, $p < 0.1$). The pattern is even clearer for web-based services. Online ticketing is strongly associated with increases in total visits (0.19, $p < 0.01$), paid visits (0.28, $p < 0.05$) and revenue (0.60, $p < 0.01$), and both digital catalogs and virtual tours are positively related to reported revenue (0.26, $p < 0.1$ and 0.52, $p < 0.05$, respectively). These results suggest that when managerial authority and day-to-day operations are integrated, digitalization tends to be deployed as part of a coherent strategy that links visibility, access and the on-site offer. In that setting, digital tools appear to reinforce one another, easing discovery and booking, enhancing the visit itself and supporting the generation of own resources (Camarero et al., 2011; Guccio et al., 2020; Turrini et al., 2008).

By contrast, *indirectly managed* museums display a more fragmented profile. Some relatively simple, low-cost technologies perform well: QR codes and proximity systems are associated with increases in paid visits (0.29, $p < 0.1$) and revenue (0.76, $p < 0.01$). Other tools, however, are linked to weaker performance. Public tablets are associated with fewer total visits (-0.52 , $p < 0.01$) and fewer paying visitors (-1.06 , $p < 0.05$), and social media activity is negatively associated with revenue (-0.85 , $p < 0.01$). Even online ticketing, highly effective under direct management, is only weakly related to total visits (0.21, $p < 0.1$) and shows no clear association with revenue. Taken together, these results point to a lack of strategic integration when governance and operations are separated. Technologies appear to be adopted selectively and in isolation, rather than embedded in a coordinated model of audience development and service provision. As a consequence, the ability of digital tools to translate into sustained visitor engagement and financial stability remains only partially realised in indirectly managed institutions (Palumbo, 2023; Pesce et al., 2019).

5.3 Accessibility

Finally, we turn to *infrastructural accessibility* (Table 8), where differences emerge in how digital technologies affect performance depending on the museum's physical accessibility and connectivity.

Museums located in areas with *weak transport infrastructure* exhibit clear gains from several forms of digitalization. On-site digital supports are positively associated with visitor flows: smartphone and tablet applications correlate with increases in both

Table 7 Heterogeneity analysis by *type of management*: Within-museum effects of digital technologies (2018–2022)

Variable	Direct management			Indirect management		
	Tot. visits	Paid visits	Revenue	Tot. visits	Paid visits	Revenue
	Digital supports					
Smartphone and tablet apps	0.04 (0.06)	0.23** (0.11)	0.03 (0.17)	0.16 (0.17)	0.26 (0.43)	0.17 (0.41)
Video and touchscreens	0.08 (0.05)	0.16 (0.10)	0.19 (0.15)	0.09 (0.11)	0.04 (0.17)	0.03 (0.30)
QR codes and proximity systems	0.00 (0.06)	−0.05 (0.12)	−0.03 (0.15)	0.06 (0.10)	0.29* (0.18)	0.76*** (0.27)
Publicly available tablets	0.06 (0.08)	0.04 (0.13)	0.01 (0.21)	−0.52*** (0.17)	−1.06** (0.49)	−0.17 (0.42)
Free Wi-Fi connection	0.06 (0.06)	0.21* (0.11)	0.21 (0.16)	0.02 (0.10)	−0.03 (0.18)	−0.09 (0.30)
	Web services					
Online ticketing service	0.19*** (0.06)	0.28** (0.13)	0.60*** (0.18)	0.21* (0.12)	0.09 (0.19)	0.35 (0.30)
Social media accounts	−0.04 (0.05)	−0.11 (0.09)	−0.17 (0.16)	−0.07 (0.11)	−0.24 (0.19)	−0.85*** (0.32)
Online virtual tours	0.03 (0.09)	−0.05 (0.18)	0.52** (0.24)	−0.02 (0.17)	0.14 (0.30)	−0.35 (0.47)
Digital catalogs	0.01 (0.06)	0.16 (0.10)	0.26* (0.16)	0.06 (0.12)	0.05 (0.35)	0.34 (0.33)
Tipo/own/reg. dummies	YES	YES	YES	YES	YES	YES
Municipal-level controls	YES	YES	YES	YES	YES	YES
Number of observations	2,169	1,278	1,274	731	512	510
Number of groups	1,382	823	819	517	366	365
r^2 (within)	0.21	0.11	/	0.23	0.13	/
r^2 (between)	0.59	0.52	/	0.62	0.68	/
r^2 (overall)	0.58	0.51	/	0.60	0.63	/
Log-likelihood	/	/	−2,517.86	/	/	−904.64

Estimates follow the same correlated REs (Mundlak) specifications as Table 5, reported separately for *public* (columns 1–3) and *private* (columns 4–6) museums

Robust standard errors clustered by museum are shown in parentheses

Statistical significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

All models include museum type, ownership, regional and year fixed effects, as well as Mundlak means of time-varying regressors

Dependent variables are winsorized at the 1st and 99th percentiles before log transformation

Estimation results with Mundlak means are reported in Table A10

total visits (0.14, $p < 0.05$) and paid visits (0.35, $p < 0.01$), and video and touchscreen installations are likewise associated with higher total visits (0.15, $p < 0.01$) and paid visits (0.21, $p < 0.05$). Some web-based services also matter. Online ticketing is linked to higher total visits (0.13, $p < 0.05$) and social media activity is positively associated with revenue (0.41, $p < 0.05$). Not all technologies, however,

Table 8 Heterogeneity analysis by *infrastructural accessibility*: Within-museum effects of digital technologies (2018–2022)

Variable	Weak infrastructure			Strong infrastructure		
	Tot. visits	Paid visits	Revenue	Tot. visits	Paid visits	Revenue
Digital supports						
Smartphone and tablet apps	0.14** (0.06)	0.35*** (0.13)	0.07 (0.15)	−0.12 (0.12)	−0.27 (0.18)	−0.25 (0.40)
Video and touchscreens	0.15*** (0.05)	0.21** (0.09)	0.18 (0.13)	−0.05 (0.11)	−0.04 (0.16)	−0.12 (0.45)
QR codes and proximity systems	0.00 (0.05)	−0.02 (0.10)	0.13 (0.13)	0.25** (0.11)	0.17 (0.18)	0.09 (0.36)
Publicly available tablets	−0.10 (0.07)	−0.32* (0.17)	−0.11 (0.17)	−0.06 (0.15)	0.26 (0.30)	1.14* (0.63)
Free Wi-Fi connection	0.05 (0.05)	0.09 (0.08)	0.07 (0.13)	−0.12 (0.15)	−0.01 (0.16)	−0.21 (0.41)
Web services						
Online ticketing service	0.13** (0.06)	0.16 (0.12)	0.23 (0.14)	0.02 (0.12)	−0.11 (0.21)	0.97** (0.45)
Social media accounts	−0.01 (0.07)	−0.08 (0.14)	0.41** (0.19)	0.13 (0.28)	0.31 (0.36)	−0.14 (0.84)
Online virtual tours	0.01 (0.05)	−0.19** (0.08)	−0.18 (0.14)	−0.20 (0.13)	−0.14 (0.19)	−1.00** (0.42)
Digital catalogs	0.01 (0.05)	0.09 (0.12)	0.17 (0.13)	0.01 (0.15)	0.03 (0.23)	0.33 (0.44)
Tipo/own/reg. dummies	YES	YES	YES	YES	YES	YES
Municipal-level controls	YES	YES	YES	YES	YES	YES
Number of observations	2,504	1,518	1,512	403	274	274
Number of museums	1,527	949	943	217	148	149
r^2 (within)	0.18	0.07	/	0.36	0.33	/
r^2 (between)	0.56	0.49	/	0.75	0.71	/
r^2 (overall)	0.53	0.47	/	0.72	0.67	/
Log-likelihood	/	/	−2,887.58	/	/	−512.42

Estimates follow the same correlated REs (Mundlak) specifications as Table 5, reported separately for *public* (columns 1–3) and *private* (columns 4–6) museums

Robust standard errors clustered by museum are shown in parentheses

Statistical significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

All models include museum type, ownership, regional and year fixed effects, as well as Mundlak means of time-varying regressors

Dependent variables are winsorized at the 1st and 99th percentiles before log transformation

Estimation results with Mundlak means are reported in Table A11

appear equally effective in these settings: publicly available tablets are associated with fewer paid visits (-0.32 , $p < 0.1$), and online virtual tours are also linked to fewer paid visits (-0.19 , $p < 0.05$). Overall, for museums that face structural disadvantages in terms of physical accessibility, digital technologies seem to act primarily as compensatory tools, helping attract visitors on-site and, to some extent, supporting the generation of own resources despite geographical constraints (Guccio et al., 2020).

Museums in areas with *strong infrastructure* display a different profile. Here, the most robust associations concern more targeted tools rather than broad digital bundles. QR codes and proximity systems are associated with higher total visits (0.25, $p < 0.05$), while publicly available tablets are positively related to revenue (1.14, $p < 0.1$). Online ticketing does not show a detectable association with visits, but it is strongly linked to higher revenue (0.97, $p < 0.05$), which is consistent with more effective management of access, pricing and on-site services in contexts where audiences can already reach the institution easily. By contrast, online virtual tours are negatively associated with revenue (-1.00 , $p < 0.05$), suggesting some substitution away from in-person, paid access. In other words, when physical accessibility is not a constraint, digital tools appear to function less as mechanisms to draw additional visitors and more as instruments for organising transactions and extracting value from an already high level of foot traffic (Di Matteo, 2023).

6 Concluding remarks

6.1 Discussion of results

This paper examines how Italian museums use ICTs and how these technologies relate to their economic performance. We distinguish between *digital supports* (interactive displays, touchscreens, apps.), which enhance the on-site experience and *web services* (online ticketing, virtual tours, social media), which extend reach and organize access. Using harmonized survey data for almost all Italian museums in 2018 and 2022, matched to municipal conditions, we study associations between these technologies and three outcomes: total visits, paid visits and ticket revenue. Two broad patterns emerge.

First, *digital supports* are primarily associated with visitor numbers. Interactive displays and touchscreens are systematically correlated with higher total and paid visits, both across museums and within museums over time. Mobile applications show similar effects, especially where physical accessibility is weak. By contrast, more generic amenities such as free Wi-Fi or lending tablets to the public show little or no association with attendance.

Second, *web services* mainly operate through access and transactions. Online ticketing systems are strongly associated with higher total visits, more paying visits and higher reported ticket revenue. This holds even after conditioning on museum type, governance and local demand factors. On the other hand, other web services play a more ambiguous role. Social media presence, though widespread, is not linked to better outcomes once other factors are accounted for. Virtual tours, while valuable as outreach, are in some cases negatively correlated with revenue, consistent with a “substitution effect”: if content is available remotely, some potential visitors may choose not to purchase admission.

Taken together, these findings suggest that *different digital technologies serve distinct strategic purposes*. On-site tools enhance the visitor experience and stimulate attendance, while web-based services improve accessibility and transaction efficiency. The results also caution against undirected digital expansion: not all tech-

nologies yield measurable gains, and some may even displace in-person visits. What matters, therefore, is not the degree of digitalisation, but the *alignment between technology, institutional mission, and operating context*.

A key contribution of the paper is to show that these effects are not homogeneous. The same technology is not equally productive everywhere. Exploiting the short panel and using a correlated random effects (Mundlak) specification, we document three systematic forms of heterogeneity:

- *Ownership*. Public museums benefit most from on-site, interpretive technologies. Interactive displays are associated with higher total and paid visits, consistent with their cultural and educational mandate. Private museums benefit more from web services: online ticketing and, in some cases, structured digital catalogs are associated with higher paid visits and revenue. For these institutions, lowering transaction frictions and signaling professional organization appears central.
- *Management*. Under *direct management*, digital tools are associated with broadly positive outcomes: online ticketing relates to more visitors and higher revenue; digital catalogs and even virtual tours correlate with higher revenue. This suggests that when strategic control and day-to-day operations are aligned, digitalization can be integrated into a coherent access and engagement model. Under *indirect management*, effects are narrower. Low-cost tools such as QR codes and proximity systems are associated with higher paid visits and revenue, but other tools (public tablets and social media) correlate negatively with performance. This points to coordination frictions when governance and operations are separated.
- *Accessibility*. Geography shapes what digital tools “do.” In museums located in areas with weak transport infrastructure, interactive displays, apps and online ticketing are associated with higher visits and, in some cases, higher revenue. Here, digital tools seem to compensate for physical remoteness. In well-connected areas, the pattern changes: online ticketing is strongly linked to higher revenue even without higher attendance, and in-gallery digital layers also correlate with greater revenue. At the same time, virtual tours are negatively associated with revenue in these accessible institutions, suggesting some displacement of paying on-site demand.

Overall, the evidence does not support a “more digital is always better” view. Instead, it suggests that digital tools are effective when they solve a concrete institutional problem: attracting audiences where demand is thin, coordinating access where demand is high, or enhancing the offer when mission and operations are well aligned.

6.2 Managerial implications

Because our dependent variables are in logs, the estimated coefficients can be interpreted as semi-elasticities: a coefficient β indicates an (approximate) percentage difference of $(e^\beta - 1) \times 100\%$ associated with adopting a given technology. This makes the results directly usable for planning. Two implications stand out.

1. *Online ticketing as an access lever.* Adopting an online ticketing system (coefficient 0.14) is associated with around 15% higher total visits, about 14% higher paid visits (0.13) and about 45% higher reported ticket revenue (0.37). To fix ideas, consider a mid-sized museum that currently receives 50,000 visits per year and reports roughly 500,000€ in ticket revenue (for example, an average ticket price of 10€). A 14% increase in paid visits would correspond to roughly 7,000 additional paying entries. A 45% increase in revenue would correspond to approximately 225,000€ more ticket income on top of the existing 500,000€. These differences are large relative to the cost of adoption. Standard digital ticketing and timed-entry systems (online booking, QR validation at entry, time-slot management) are typically provided as modular services and can be integrated with existing front-of-house operations without major capital investment, especially in medium-sized institutions (Guccio et al., 2020; Turrini et al., 2008). The implied gain in revenue in the example above therefore comfortably exceeds typical recurring costs for such systems. Beyond the direct financial effect, online ticketing lowers the practical cost of visiting, especially for tourists and school groups, who can reserve in advance, and produces reliable data on inflows and congestion that can be used to plan staffing, opening hours and activities (Camarero et al., 2011; Guccio et al., 2020).
2. *Interactive interpretation as an engagement lever.* Interactive displays and other on-site interpretive technologies are associated with higher attendance, especially in publicly owned, directly managed museums and in museums located in less accessible areas. In the panel estimates, the presence of interactive video and touchscreen installations is associated with roughly 13% higher total visits (coefficient 0.12) and about 20% higher paid visits (0.18). For a small municipal museum receiving 15,000 visits per year, a 13% increase in total visits implies about 1,950 additional visits annually. A 20% increase in paid visits implies a similarly meaningful increase in paying audiences. Operationally, this scale of change can mean fuller guided tours, more school groups and more repeat educational programming, precisely the forms of outreach and local anchoring that publicly owned institutions are mandated to deliver (Federici & Parisi, 2022; Sandell, 2003). For these institutions, this is not a by-product of digitalization; it is central to their cultural mission.

These findings suggest a simple sequencing logic for directors and policymakers:

1. *Guarantee access.* Prioritize online ticketing (advance booking, timed slots, digital validation). This reduces barriers to entry and produces actionable data on demand.
2. *Upgrade the core visit.* Invest in focused, high-quality interactive interpretation in key rooms or collections. The aim is to deepen the experience where visitors already concentrate, not to digitize every exhibit.
3. *Tailor to context.* In large, centrally located museums with stable footfall, prioritize ticketing, capacity management and pricing tools. In smaller, publicly owned museums in peripheral areas, prioritize on-site interpretive technologies and targeted outreach to schools and first-time visitors.

6.3 Future research

Three main limitations point to promising directions for future research.

First, our performance measures, total visits, paid visits and ticket revenue, are relevant for governance and funding purposes, yet they overlook some dimensions of cultural value such as learning, inclusion, audience renewal and long-term reputation. Future studies could link ICT adoption to broader outcomes, for instance distinguishing first-time from repeat visitors, assessing educational impact, or capturing perceived quality and engagement. This would connect digital transformation strategies more directly to the museum's cultural mission.

Second, our panel currently includes only two waves (2018 and 2022). Such a short time horizon prevents us from distinguishing temporary boosts, such as those driven by the novelty of a new digital installation, from enduring structural changes. Extending the panel over additional years would allow researchers to evaluate whether digital investments produce lasting effects on audience composition, financial resilience and institutional sustainability.

Third, while we observe who owns and manages each museum, we do not capture how it is managed. Our data lack information on managerial quality, staff capacity, contractual arrangements, or pricing autonomy. More granular governance data, covering decision-making over digital content, programming and ticketing, would clarify why similar technologies yield divergent results across organizational settings.

Finally, our findings on virtual tours raise an important open policy question. Remote access can expand reach, but for highly accessible and high-demand museums it may also substitute for in-person, paying visits. Future research should identify the conditions under which online access complements rather than displaces physical attendance. This distinction is critical for cultural policy, as it bears directly on the trade-off between accessibility and financial sustainability.

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Data availability All data used in this study are from publicly accessible sources (as accurately described in the Online Appendix) and will be made available upon request to the corresponding author.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

Ethical approval and consent to participate No ethics approval was required for this study as it involves only secondary analysis of publicly available data.

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