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Article

Demystifying the Use of Open-Access Data in Smart Heritage Implementations

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Abstract: Smart Heritage, a concept closely linked to Smart Cities and Smart Tourism, is an emerging field focused on enhancing heritage identity, visitor experience, and cultural sustainability. While initial frameworks have been developed, there is a gap in applying Smart Heritage at the precinct level, especially in large-scale heritage sites. This study addresses this gap by examining how open-access data can be utilised in a real-world case study of Chinatown Melbourne, a key urban heritage precinct. Data sources include archival maps, open-access databases, and 3D models provided by the local city council, covering resources such as on-street parking, pedestrian activity, microclimate, and dwelling functionalities. This study employed a structured methodology that transitions from global best practices to local applications, linking these data resources to Smart Heritage applications and identifying opportunities for improving urban management, heritage curation, and the tourism experience within the case study precinct. The findings offer practical insights for researchers and policymakers, demonstrating how data can support the development of culturally sustainable and technologically integrated heritage precincts. Future research should explore additional data types and case studies to further advance the field of Smart Heritage.

Keywords: Smart Tourism; Smart Heritage; urban heritage; open-access data; cultural sustainability; Chinatown Melbourne



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1. Introduction

As a recently established field, Smart Heritage has become a heated topic derived from the Smart City concept, often intertwined with Smart Tourism. Most of the current research in the field has a theoretical focus and framework establishment. Batchelor et al. (2021) define the discourse as a convergence between the Smart City and Heritage disciplines, where autonomous and automatic capabilities, innovation of smart technologies, and contextual and subjective interpretation of the past intertwine [1]. Smart Heritage seeks to adopt participatory and collaborative approaches, making cultural data more available to the public and consequently increasing opportunities for interpretation, digital curation, and innovation. It can connect tangible and intangible heritage with its visitors in both the real and virtual worlds [2]. Recent studies in the field argue that many of the current Smart Heritage implementations are still at the digitisation stage. Geng et al. (2023a) argue that Smart Heritage differs from digital heritage by emphasising autonomous capabilities. However, it is undeniable that both digital and Smart Heritage require the inputs and outputs of data, making open-access data essential for both transformations [3]. The current transition phase for many heritage sites from being digital to being smart remains mysterious for many policy and decision-makers in terms of the practical output of Smart Heritage implementations. Existing literature in Smart Heritage primarily pivot around theoretical frameworks and standalone digital heritage applications, with a significant gap in practical implementations using real-world data. Hence, this study addressed this gap by analysing the role of open-access data in transformation of heritage precincts to Smart Heritage.

As an iconic heritage precinct in the heart of Melbourne, Chinatown Melbourne is one of the oldest ethnic enclaves in Australia. Established during the gold rush in the 1850s, it has transformed from a stigmatised ghetto to a vibrant tourist destination, reflecting the broader multicultural narrative of Australia [4,5]. The precinct's architectural styles and demography have been well-documented, yet its spatial characteristics, such as the street network within the urban grid, visibility relationships, and the interaction between buildings and streets, remain underexplored [6]. Existing studies have also offered insights into the heritage conservation aspects of the precinct, aiming to unpack shifts of urban identity assessments in heritage frameworks under the impact of COVID-19 [7]. As an urban heritage precinct situated in the city centre, different categories of open-access data of the precinct have been made available by the local city council (the City of Melbourne). The City of Melbourne also has a strong emphasis on the goal of creating a Smart City on their strategic agenda, including a range of innovative initiatives and pilot projects aimed at enhancing urban sustainability, digital transformation, and community wellbeing. Key initiatives include the Melbourne Renewable Energy Project to support 100% renewable energy, Power Melbourne to develop neighbourhood-scale batteries, and the Emerging Technology Testbed for piloting smart solutions. Pilot projects such as the Digital Wayfinding Project test new technologies for improving city services and enhancing urban liveability [8]. However, limited projects have been conducted in the scope of Chinatown Melbourne itself or with a focus on heritage. The precinct's unique spatial configuration and historical depth, as well as the availability of detailed open-access datasets, make it an ideal case study choice for testing Smart Heritage strategies. These factors, coupled with its central location in Melbourne and the uniqueness in the tourism market, present a rare opportunity to explore data-driven Smart Heritage within a complex urban context. The precinct is yet to fully utilise these resources with the potential implementation of Smart Heritage strategies. A significant gap in existing research is the lack of emphasis on how to implement such strategies practically. To demystify this tactic, this study used current best practices relevant to Smart Heritage implementations to advise potential Smart Heritage strategies with the assistance of currently available open-access data. Based on a problem-based foundation, this study uses Chinatown Melbourne as the case study to best define the study scope and provide practical recommendations for the selected case study, transferable to heritage sites with similar open-access data resources. By applying the analysis to Chinatown Melbourne, the research demonstrates the practical applicability of Smart Heritage strategies, thereby bridging the gap between theoretical frameworks and real-world applications with feasible data. The primary aim of this study is to examine the currently available open-access data for Chinatown Melbourne and how these datasets can be employed for its potential Smart Heritage transformation. Future studies are recommended to test the methodology framework with other heritage sites.

2. Literature Review

2.1. Heritage Tourism in the New Era

With the use of technological innovations, heritage tourism has revolutionised how cultural heritage sites are conserved, managed, and experienced in the new era. With tools such as augmented reality (AR), virtual reality (VR), and digital platforms, heritage sites can now offer interactive and immersive experiences. As demonstrated by Chen et al. (2024), AR applications can overlay historical information onto physical landscapes, enabling tourists to visualise heritage sites in their original form, thus enhancing the depth of their experience [9]. Similarly, Jia et al. (2023) emphasised the importance of AR in recreating intangible heritage elements, such as vanished buildings, for educational purposes [10]. Virtual museums and online platforms, accelerated by the pandemic, have become key tools for maintaining engagement with heritage sites globally. Suanpang and Pothipassa (2024) explore how the integration of artificial intelligence (AI) and the Internet of Things (IoT) facilitates real-time, remote heritage engagement, which opens up cultural experiences to a broader audience [11]. Similarly, Perfetto (2018) discussed how digital platforms allow for

a more inclusive access to heritage sites, catering to those who cannot physically visit these locations [12].

The balance between technological innovation and cultural authenticity is a common concern. Chapagain (2017) suggests that while digital tools can enhance the visitor experience, they may risk commodifying heritage sites, thus diminishing their historical and cultural value [13]. This sentiment is echoed by Bastidas-Manzano et al. (2020), who assert that careful management is required to ensure that digitalisation supports rather than undermines the authenticity of cultural sites [14]. At the same time, digital tools offer substantial benefits for sustainable heritage management. For instance, Song et al. (2023) and Maulina et al. (2023) explore how IoT-enabled monitoring systems can collect real-time data on environmental conditions and visitor flow, which assists in minimising the physical impact on sensitive heritage sites. Giuffrida et al. (2021) further explored how digital tools such as Geographic Information Systems (GIS) and Building Information Modelling (BIM) are increasingly being used to monitor and manage heritage conservation [15].

In urban contexts, particularly precincts like Chinatown Melbourne, such technologies can ensure that heritage conservation efforts align with broader urban planning and sustainability goals [16,17]. Nevertheless, Kalia et al. (2022) and Jeong and Shin (2019) point out the challenges related to access and infrastructure [18,19]. They observe that heritage managers and visitors may not always have access to the necessary digital infrastructure, creating a digital divide that must be addressed to ensure that these technologies can be fully utilised. Moreover, Valentini et al. (2018) point out that heritage sites in less economically developed regions often face difficulties in acquiring and maintaining such advanced technological systems [20]. Thus, the new era offers unprecedented opportunities for heritage conservation and engagement, yet it also introduces challenges regarding authenticity, accessibility, and sustainability. For urban heritage precincts like Chinatown Melbourne, the key to success lies in adopting these technologies thoughtfully, ensuring that they enhance both cultural preservation and visitor engagement.

2.2. Smart Tourism in the Heritage Context

This section of the literature review will focus on Smart Tourism in the heritage context, which aims to focus on the autonomous ability of these innovative technologies in the new era. Smart Tourism has become integral to managing heritage sites more effectively while enriching the visitor experience. In the context of heritage, Smart Tourism technologies are increasingly being applied to create more personalised, sustainable, and engaging experiences for visitors. Tsang and Au (2023) explore how the implementation of Smart Tourism systems, including mobile apps and AR experiences, significantly enhance visitor engagement at heritage sites by providing tailored, real-time information [21]. Calle-Lamelas et al. (2024) expands on this by discussing how smart destination models have been successfully implemented in Spanish World Heritage Cities, improving both the management of tourist flows and the sustainability of these sites [22]. The data-driven insights generated by these systems allow heritage managers to monitor visitor preferences, manage crowds, and improve site conservation efforts. This is especially relevant for densely populated heritage precincts such as Chinatown Melbourne, where the influx of visitors can threaten the site's long-term sustainability. Further, smart technologies support operational sustainability at heritage sites. Jeong and Shin (2019) and Maulina et al. (2023) highlight the use of real-time analytics to monitor visitor behaviours, enabling managers to predict peak times and adjust site operations accordingly [19]. Salvia et al. (2016) also highlight the importance of integrating Smart City infrastructures into heritage precincts to enhance resource efficiency, especially in areas like energy and water usage [23]. Similarly, Mitro et al. (2022) find that IoT sensors can be employed to monitor microclimate conditions, preserving both the natural and built environment of heritage sites [24].

However, Kalia et al. (2022) points out that the cost of implementing Smart Tourism technologies and the complexity of these systems can be prohibitive for some heritage sites, particularly in less developed regions [18]. They also point out that not all heritage

sites have the infrastructural capacity to support such technologies, which is a challenge that policymakers must address. Moreover, there are concerns that an over-reliance on technology could overwhelm visitors or detract from the authenticity of the heritage experience. Salvia et al. (2016) also stresses the need for collaborative governance structures to ensure smart technologies are implemented in ways that benefit both tourists and heritage sites [23]. Jeong et al. (2022) emphasise that while personalisation is valuable, smart technologies should not overshadow the cultural and historical significance of the site [19]. Despite these challenges, the potential of Smart Tourism to enhance heritage site management and visitor engagement is immense. Pinke-Sziva (2024) shows that data analytics could help heritage managers better understand visitor preferences, allowing for more targeted marketing and improved visitor experiences [25]. Zubiaga et al. (2019) also emphasise the importance of using smart technologies to manage overtourism in historic centres, which can cause significant damage to cultural sites [26]. Integrating smart technologies into urban heritage precincts, such as Chinatown Melbourne, could transform the precinct into a leading example of how technology and culture can coexist harmoniously, supporting both heritage conservation and contemporary urban development.

2.3. Smart Heritage and Practical Implementations

Limited studies have been undertaken to address the practicality of Smart Heritage implementations, which is a concept derived from Smart City and Smart Tourism [27]. Some studies have pointed out that Smart Heritage utilises tools such as Geographic Information Systems (GIS), BIM, and the Internet of Things (IoT) to create intelligent support mechanisms for sustainable tourism and heritage conservation [26,28]. For instance, the Smart Heritage City (SHCITY) project utilises IoT and big data to monitor tourist flows, helping manage visitor impact on historic centres and prevent overtourism [26]. Portable sensor technologies, such as non-invasive contact sensors, further support the analysis of cultural heritage and control damage to artifacts [20,29]. Adaptive reuse projects, such as those in Siracusa, Italy, highlight the importance of evaluating the impacts of heritage conservation on urban development, using indicators that assess physical, cultural, social, environmental, and economic systems [29]. Despite progress, many Smart Heritage projects still focus predominantly on environmental sustainability, often neglecting advanced technological criteria and social sustainability issues [30]. Using the European Capital of Smart Tourism (ECST) competition best practices of 2020–2022, Geng et al. (2023) argue that attributes like accessibility, informativeness, interactivity, and personalisation are essential for creating positive Smart Tourism experiences, influencing tourists' engagement and satisfaction [3]. It is important to differentiate between being digital and being smart, where the autonomous ability helps to define the two. Their study also asserts that many existing projects are digital heritage without the autonomous ability embedded, making them not fully Smart Heritage. Overall, the literature review concludes that open-access data have been utilised widely in heritage sites, particularly urban heritage. However, there is a lack of research on how Smart Heritage can be best intertwined with open-access data and achieve the autonomous aspects with directions in practical applications. Hence, this study aims to fulfil this research gap with Chinatown Melbourne as an urban heritage example, aided by best practice examples from (ECST) 2020 to 2024.

2.4. Open-Access Data and Heritage Management

Open-access data play a pivotal role in preserving and managing heritage by providing accessible information that can support diverse conservation efforts. For heritage in the urban context (urban heritage), such a role is even more critical, as the surrounding contexts of urban heritage sites can be complex. The integration of digital analytical tools and 3D modelling/documentation, such as Building Information Modelling (BIM), has significantly enhanced heritage analysis, leading to improved quality and cost reduction in conserving heritage, particularly in an urban setting [15,31]. Researchers have also pointed out that open-access data not only enhance the reconstruction of historical and

social memories but also transform the role of historians and the narrative of historical events. Social media and open data sources have been widely engaged in to promote heritage sites and receive feedback from visitors, aiding the revitalisation of many heritage sites worldwide [32]. Similarly, spatially enabled web applications with open-access data demonstrate the potential of integrating multiple data sources for efficient urban heritage monitoring, management, and reporting [33]. Remote sensing and open-source tools, such as Sentinel-2 data and microclimate datasets, have proven beneficial in archaeological investigations and monitoring urban sprawl around cultural heritage sites in the urban region [24,34]. Based on a participatory approach, Shehata (2022) asserts that engaging residents and adopting innovative solutions in urban heritage conservation can improve the vitality and sustainability of historic urban centres, as evidenced by studies in Jeddah and Amman [35]. Various cultural heritage institutions are facilitating open dataset development and improving data quality, such as linked open data (LOD), essential for AI-based heritage assessments [36]. Overall, existing research suggests that open-access data are integral to the effective conservation and management of urban heritage, fostering informed decision making and sustainable urban development.

3. Materials and Methods

To fulfil the primary research aim, this paper addresses three key research questions:

1. How are key best practices in the field utilising Smart Heritage strategies?
2. What types of open-access data are available for Smart Heritage implementations in Chinatown Melbourne?
3. What strategies from best practices can be adapted to the precinct with the aid of available open-access data?

Table 1 illustrates the methodology framework adopted for this study. To answer the first research question, Stage 1 of the study reviews data from the European Capital of Smart Tourism (ECST) competition. Established in 2019, the ECST is internationally recognised for showcasing best practices in Smart Tourism cities across Europe, particularly in the 'cultural heritage and creativity' category. The competition evaluates initiatives based on effective activity programs and suitability as Smart Tourism Cities, alongside three other categories: 'sustainability', 'accessibility', and 'digitalisation'. The study by Geng et al. (2023b) analyses leading examples of Smart Tourism practices from 2020 to 2022, offering a methodological foundation for this research by highlighting how place identity is represented in urban-scale Smart Heritage projects [3]. Extending this foundation, this study reviews the best practices from the 2023 and 2024 ECST competitions with content analysis [37]. The approach is used to categorise best practices based on their objectives and implementation strategies [38,39]. Differences and shifts in focus within the 2023 and 2024 best practices, compared to previous years, are addressed in the discussion section. The findings are combined and compared with the earlier study's categories of best practices and presented in the results section. The 'sustainability' and 'accessibility' categories are considered only if a project is related to cultural heritage, thereby narrowing the focus to the 'cultural heritage and creativity' and 'digitalisation' categories, which align with the study's scope and selection criteria. The results from this stage will be explored in the results section, where the categorised best practices from the ECST competition will be analysed to determine their relevance to Smart Heritage strategies in Chinatown Melbourne, focusing on how key patterns and trends can inform local applications. To address the second research question in Stage 2, a case study method is employed, with Chinatown Melbourne serving as the primary case. The study first explores existing open-access data and 3D models provided by the local city council, selecting the most suitable datasets that can facilitate Smart Heritage transformation. Melbourne's open-access data platform encompasses seven categories with 235 datasets: transportation, sensors, business, environment, people, property, and city council [8]. Relevant real-time datasets, such as pedestrian counting and on-street parking from the sensors category, are selected for their potential to inform dynamic heritage management. Additionally, non-real-time data, such as the 3D historic models from the

property category, are incorporated due to their relevance to the heritage context. The selection of these datasets is guided by their ability to address key challenges in heritage management, such as monitoring visitor impact and public space utilisation. Data quality, completeness, and accuracy are verified through cross-referencing with historical data and city council reports to ensure robustness. The case study approach is effective for emerging research areas where frameworks and theories are still being established [40]. This approach provides in-depth insights into complex, context-dependent phenomena such as Smart Heritage implementations [41,42]. Due to its capacity to link theoretical concerns with existing heritage sites, the case study method is well-suited to this research [16,43,44]. However, this approach may limit the generalisability of findings across different contexts. Future research should incorporate comparative case studies across multiple heritage sites to validate the findings [42]. Data analysis in this stage involves evaluating the potential uses and limitations of the available datasets concerning the precinct's heritage management, while contextualising it with the case study. Each dataset is examined for its relevance, potential applications, and ability to address specific challenges within Chinatown Melbourne. This analysis is primarily qualitative, discussing the strengths and gaps in the data and exploring how future implementations could be enhanced by integrating new data sources or sensors for more effective heritage management. The results section presents insights from this stage, focusing on the specific applications of the selected datasets, while addressing challenges related to visitor management, space utilisation, and the integration of technology in heritage conservation. For the third research question, Stage 3 of the study consolidates findings from the previous stages by aligning the available open-access data from the City of Melbourne with five relevant best practice projects. A comparative case study approach is used to analyse these projects based on their objectives and strategies, considering the suitability of the datasets for the local precinct [45]. One current Smart City project piloted in Chinatown Melbourne was selected for comparison, as it is the only initiative located within the precinct according to the City of Melbourne. This comparative analysis identifies key strategies that align with Chinatown Melbourne's unique cultural and urban context, evaluating their transferability to local conditions. By linking global best practices with the available datasets, this study provides guidance for policymakers and decision-makers on how data can be effectively used in Smart Heritage transformations. Although the reliance on European best practices presents a limitation, the study acknowledges their value as initial benchmarks in the absence of widely implemented Smart Heritage projects outside of Europe. Future research should explore case studies from other regions to create a more comprehensive understanding of global Smart Heritage applications. The results section addresses the findings from this stage, evaluating the effectiveness and transferability of the identified best practices to assess their suitability for Chinatown Melbourne's Smart Heritage transformation.

This study follows a structured approach, ensuring a clear relationship between the stages of the research and the research questions. Stage 1 addresses the first research question by reviewing best practices from the European Capital of Smart Tourism (ECST) competition, identifying key Smart Heritage strategies relevant to cultural heritage and digitalisation. In Stage 2, these best practices are matched to the local context of Chinatown Melbourne by analysing specific open-access datasets, such as pedestrian counting and on-street parking, to assess their suitability for heritage management. The findings from Stage 1 and Stage 2 are combined to inform Stage 3, which responds to the third research question by determining how best strategies from other cities can be adapted to Chinatown Melbourne using the available data. By integrating the insights from global best practices (Stage 1) with the practical applications of local datasets (Stage 2), Stage 3 also evaluates the transferability and effectiveness of these strategies in the precinct. This progression from global insights to local implementation ensures that each stage builds on the previous one, deepening the logical relationship between the methodology, results, and discussion sections. Previous studies have employed a similar approach, demonstrating

the value of linking global strategies with local contexts to enhance the applicability of smart solutions [46–48].

Table 1. Stages of the study and research questions.

Focus	Global Best Practices and Strategies	Local Datasets	Local Strategies and Implementations
Stage	Stage 1	Stage 2	Stage 3
Scope	Review of relevant ECST best practices from 2019 to 2024	Scrutinise available open-access data within the case study (Chinatown Melbourne)	Identify how Chinatown Melbourne can best utilise available resources for Smart Heritage implementations
Research question	How are key best practices in the field utilising Smart Heritage strategies?	What types of open-access data are available for Smart Heritage implementations in Chinatown Melbourne?	What strategies from best practices can be adapted to the precinct with the aid of available open-access data?
Key method	Content analysis	Case study	Comparative case study
Data collection	Best practices from the European Capital of Smart Tourism (ECST)	Datasets from the City of Melbourne data platform	Consolidation of findings from Stages 1 and 2
Data analysis	Content analysis	Contextual analysis	Comparative analysis

4. Results

The results are structured to reflect the progressive stages of the study, starting with global Smart Heritage best practices, followed by the analysis of local datasets for Chinatown Melbourne, and concluding with the application of these insights to inform practical strategies for the precinct.

4.1. 2023 and 2024 Best Practices from the ECST

Stage 1 highlights key best practices and strategies from the ECST competition, specifically focusing on initiatives that effectively integrate cultural heritage. These practices serve as a foundation for identifying approaches that can be adapted to enhance Smart Heritage in Chinatown Melbourne. As Smart Heritage is derived from the Smart City concept and most current innovations in the field are covered and addressed as Smart City projects, this study extracted the two most relevant major categories in the ECST compendium to study key strategies that current Smart Heritage projects use, including cultural heritage and creativity, as well as digitalisation. This methodology was tested in the study by Geng et al. (2023a) to elucidate how urban identity is mapped in current Smart Heritage projects [3]. This study adopts such a methodology but aims to study how data and practical implementations are projected in the current best practices of Smart Heritage. Each major category includes one to five subcategories with several projects included. Table 2 showcases all the subcategories within the best practice list of ECST. Projects prior to 2023 do not have specific years in the table due to the competition arrangements.

Table A1 in Appendix A shows the projects that are relevant to Smart Heritage or have been applied in a heritage context. Upon retrieving best practices from the 2023 and 2024 ECST compendium, the next step of the study is to consolidate and combine the findings of the previous best practices within the ECST compendium and the 2023 and 2024 ones, integrating both sets of data. As the results from Geng et al. (2023a) concern previous ECST best practices before 2023 within the Smart Heritage context, this study reframes their findings to best combine the tables from both studies [3]. This step is essential for the case study comparative case study identification.

Table 2. Full list of themes and subcategories of ECST under ‘cultural heritage and creativity’ and ‘digitalisation’ in 2023 and 2024 ECST.

Best Practice Category in the ECST 2024	Subcategory	Project Themes
Cultural Heritage and Creativity	Revival of Cultural Heritage	(2024) Experiential Tourism Projects; Cultural Events and Festivities; Preservation of Cultural Heritage; Establishing Nation Institution; Preserving the Traditional Spirit (2023) Sustainable Cultural Gastronomy, Transformative Cultural Events, International Cultural Partnerships, Experiential Tourism Projects, Capitalising on Cultural Spirit
	Creating Communal Infrastructure	(2024) Creating a Cultural Company (2023) Creating Communal Infrastructures: Smart Public Buildings, Creating New Public Space
	Cultural Heritage Usage for New Creativity	(2024) Promotion of Creative Industries; Use of New Technologies; Creating New Cultural Spaces (2023) Public Street Art, Providing Easy Access to Cultural Activities, Creative Perspectives on Discovering Cities, Creating New Cultural Heritage, Creating New Cultural Industries
	Maintaining Cultural Heritage	(2024) Community Engagement; Cultural Heritage and Creativity Strategies (2023) Maintaining Cultural Heritage: Cultural Heritage and Creativity Strategies, Community Engagement, Integrating All into Cultural Heritage
Digitalisation	Facilitating Information for Specific Groups	(2024) Digital Innovation in City Guides; Digital Tours and City Exploration (2023) Digital Tours and City Exploration, Augmented Reality in Tourism, Digital Innovation in City Guides
	Collecting Information for Smart Management	Open Data for Improving Tourism; Smart Urban Management; Digital Municipal Solutions; Digital Solutions in Business
	Transformation into Digital Knowledge Sharing	Digital Access to Information; Promotion of Digital Innovations; Digitalisation in Cultural Spaces; Digital Culture and History Experience
	Innovative Mobility through Digitalisation	Smart Benches; Local Community Engagement; Knowledge and Technological Capabilities

4.2. Types of Open-Access Data of the Case Study Area Provided and Best Matched Case Studies

Building on the global insights from Stage 1, Stage 2 focuses on analysing local open-access datasets, matching these datasets with relevant best practices to inform how they can be effectively applied in the Chinatown Melbourne case study. To highlight key case studies from the ECST, the study presents five initiatives as examples of best practices, aligned with five key open datasets provided by the City of Melbourne: open-street parking, pedestrian counting, microclimate, dwelling functionality, and the Historic 3D model. Additionally, the study identifies one current pilot initiative in Melbourne’s Chinatown. Although this pilot initiative does not have a specific tourism or heritage focus, presenting it as a case study allows for comparison with other examples, helping to elucidate potential smart strategies and relevant data types. The results are presented in Table 3 below, which are further discussed and analysed in the following sub-sections according to each data category.

Table 3. Key sample case studies selected from the ECST and Chinatown Melbourne.

Category of Information	Smart Parking System (Pafos)	Discovery Trails City	Smart Kalea Platform San Sebastian	Zagreb Smart City Hub	3D Reconstruction of Alcazar of Seville	Laneway Waste Management Pilot
Location	Pafos, Cyprus	Dublin, Ireland	San Sebastian, Spain	Zagreb, Croatia	Seville, Spain	Melbourne, Australia
Implementation Goal	Optimises parking management using real-time sensor data to enhance parking efficiency and reduce congestion across over 3000 parking spaces.	Interactive platform offering AR-enhanced historical and cultural trails for visitors to explore Dublin's heritage through immersive digital storytelling.	Improves energy efficiency in commercial and residential areas using smart meters, monitoring systems, and renewable energy solutions.	Integrates advanced digital infrastructure (e.g., high-speed broadband, smart sensors) to support sustainable urban development and smart applications.	Virtually recreates Seville's historic Almohad Mosque, allowing immersive exploration of its architectural features and historical significance.	Uses IoT devices and CCTV analytics to optimise waste management and improve laneway cleanliness.
Statue of the Project	In-use	In-use	In-use	In-use	In-use	Completed, now expending to other laneways
Main Source	https://smartparkingsystems.com/en/smart-parking-systems-in-pafos-cyprus/ (20 August 2024)	https://dublindiscoverytrails.ie/ (20 August 2024)	https://www.smartkalea.eu/en/smartkalea/energy-efficiency (20 August 2024)	https://english-smart-city-zagreb.hub.arcgis.com/pages/strategic-area-digital-infrastructure (20 August 2024)	https://voyagerseville.com/en/3d-reconstruction-of-the-mosque-of-seville/ (20 August 2024)	https://participate.melbourne.vic.gov.au/emerging-tech-testbed/bullens-lane (20 August 2024)
Full Datasets	<ol style="list-style-type: none"> 1. Parking occupancy data from in-ground sensors (LoRaWAN® and BLE technology). 2. Real-time availability of parking bays. 3. Payment and usage data from the Pafos Smart Parking mobile app. 4. Geographic location and type of parking spaces (e.g., disability, short-term). 	<ol style="list-style-type: none"> 1. Digital content data (AR experiences, historical narratives). 2. Visitor interaction and engagement data from the app. 3. Geospatial data for themed trail routes (e.g., Docklands, Castleknock). 4. Pedestrian flow. 	<ol style="list-style-type: none"> 1. Energy consumption data from smart meters in residential and commercial properties. 2. Water usage and cost-saving analysis. 3. Data on renewable energy adoption and purchasing patterns. 4. Microclimate. 	<ol style="list-style-type: none"> 1. Broadband coverage and usage data. 2. Sensor data for urban services and environmental monitoring. 3. Integrated data from smart applications (e.g., public services, mobility). 4. Spatial and dwelling analytical data. 	<ol style="list-style-type: none"> 1. Architectural and historical data of the mosque. 2. 3D spatial data for virtual modelling. 3. Digital imagery and photogrammetry data for detailed reconstructions. 	<ol style="list-style-type: none"> 1. CCTV footage and analytics data for waste disposal patterns. 2. IoT device data on bin usage and compactor operation. 3. Sensor data on blockages, waste levels, and system downtime.
Matching Data Type with the City of Melbourne	On-street parking (real-time)	Pedestrian (real-time)	Microclimate (real-time)	Dwelling functionality	3D modelling	Sensor installed in bins (real-time)

4.2.1. On-Street Parking Data

As part of its commitment to enhancing transparency and public services, the City of Melbourne has made on-street parking data openly accessible, facilitated by 6000 in-ground sensors installed throughout the city. These sensors detect vehicle movements through individual parking bays, providing information on bay availability, parking limits, and disability parking restrictions (Figure 1). The City of Melbourne also provides recommendations for developers, entrepreneurs, and the public who wish to use the open-access dataset, including improving parking efficiency, reducing time spent searching for parking, enhancing traffic flow, and lowering emissions.

From the 2023 and 2024 ECST best practices, an increasing number of projects focus on evolving traffic and parking with smart solutions. This study identifies that open-street parking data can enhance initiatives like Park Smarter (Athens and Dubrovnik), Smart Parking System (Pafos), Smart Traffic Control for Tourists and Locals (Malaga), and the First Autonomous Bus in Denmark (Aalborg). These projects involve parking and traffic

control systems where access to on-street parking data would directly enhance functionality and user experience [49]. Existing research suggests that Chinatown Melbourne's spatial layout consists of narrow main streets and open and closed laneways. Aligning with the Chinatown Action Plan 1985, the main street accommodates both pedestrians and vehicles to maintain a bustling streetscape that reflects Chinese characteristics, a concept proposed by Geng et al. (2023) as 'Chinatown characteristics'. Due to its mixed-use nature and central location, traffic and parking have been long-term issues in the area. This conflict between the original urban identity and functionality, as experienced in Chinatown Melbourne, can be effectively addressed with smart solutions through automated data collection on traffic and parking [50]. Like the best practices identified, smart parking and traffic control systems can help the precinct better manage vehicle influx, ensuring efficient traffic and parking control decisions are implemented.



Figure 1. On-street parking sensor locations at and around Chinatown Melbourne (source: Open-access data platform by the City of Melbourne).

Integrating open-access on-street parking data has the potential to greatly enhance traffic and parking management in Chinatown Melbourne. Given the precinct's narrow streets and mixed pedestrian and vehicular spaces, smart parking solutions are essential to maintaining its vibrancy and accessibility. Drawing on ECST best practices, such as the Smart Parking System in Pafos (Table 3), which uses real-time data from in-ground sensors (LoRaWAN[®] and BLE technology) to manage over 3000 parking spaces, Chinatown Melbourne could adopt a similar system. It provides real-time availability of parking bays, payment, and usage data via the Pafos Smart Parking mobile app and maps the geographic location and type of parking spaces, serving as an ideal model for Chinatown Melbourne to enhance its parking management.

Implementing these systems could also resolve long-standing challenges noted in the Chinatown Action Plan (1985), which stressed the importance of balancing pedestrian accessibility with vehicular movement to preserve the precinct's streetscape and cultural identity. A smart traffic management system, similar to the Park Smarter initiatives in Athens and Dubrovnik, would allow the City of Melbourne to make data-driven decisions on parking availability, pricing, and traffic routing. This could reduce congestion, particularly during peak times, by directing drivers to available parking spaces or alternative locations, ultimately reducing illegal parking and enhancing pedestrian safety. Furthermore, integrating parking data with other datasets, such as pedestrian and microclimate

data, would facilitate a more holistic approach to precinct planning, ensuring that infrastructure developments meet both vehicular and pedestrian needs. Aligning these smart solutions with the precinct's 'Chinatown characteristics' would foster a balance between heritage values and modern urban functionality, positioning Chinatown Melbourne as a model for integrating Smart Heritage practices in mixed-use urban environments.

4.2.2. Pedestrian Counting Data

Melbourne City's automated sensor network provides real-time information on pedestrian activity, which is crucial for maintaining city vibrancy and vitality [51,52]. There is a proven link between a city's economic health and safety and the convenience of pedestrian experiences [53]. The City of Melbourne uses these data to understand how people move through different areas at various times, aiding decision making and future city planning [54]. Chinatown Melbourne, centrally located within the Hoddle Grid, benefits from this data collection, with Figure 2 below showing the current locations of pedestrian counting sensors in the precinct.

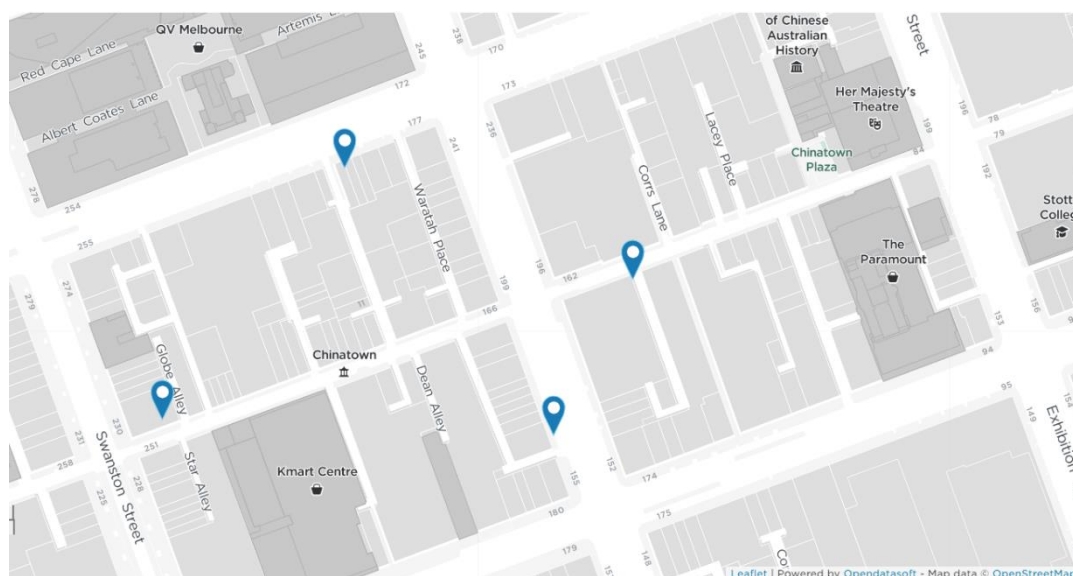


Figure 2. Pedestrian counting sensor locations at and around Chinatown Melbourne (source: open-access data platform by the City of Melbourne).

Incorporating pedestrian counting data has been a key feature of many ECST best practices relevant to Smart Heritage. One notable application is its integration with mapping and trail apps, such as A Walkable City (Barcelona), Smart Tourist Trails (Malaga), and the Discovery Trails City App (Dublin). These applications use pedestrian flow data to recommend optimal tourist routes, enhancing the visitor experience through digital visualisations and AR features [55–57]. However, for Chinatown Melbourne, where pedestrians may pass through the precinct unintentionally, categorising visitors captured by the sensor or placing sensors outside cultural centres like the Museum of Chinese Australian History to collect heritage/tourist visiting data is essential [58]. Some of the aforementioned best practices combine sensor data with visitor feedback. Similarly, for Chinatown Melbourne, pedestrian counting data should be interpreted alongside visitor feedback to enhance the visitor experience. Several ECST best practices involve urban planning, tourism, pedestrian experiences, and mobility, where pedestrian counting data offer insights towards achieving Smart Heritage goals. These projects include Repositioning Málaga as the 'City of Museums' (Malaga), Old Becomes New (Bordeaux), Generating Values for Tourists (Copenhagen), The Festival of Lights (Lyon), Understanding Local Sentiment Toward Tourism (Dublin), Data Collection and Sharing for a Better Tourism Experience (Dubrovnik), and Innovation in Mobility (San Sebastián).

Pedestrian counting data have also been a critical tool for urban planning, tourism, and mobility in various ECST projects, providing insights into achieving Smart Heritage goals. For example, initiatives such as Repositioning Málaga as the ‘City of Museums’, Old Becomes New (Bordeaux), and Data Collection for a Better Tourism Experience (Dubrovnik) demonstrate how pedestrian data can inform decisions on infrastructure improvements, visitor flow, and tourism strategies. In the Discovery Trails City project (Dublin), an interactive platform uses AR and historical narratives to engage visitors with Dublin’s heritage, supported by pedestrian data, geospatial mapping, and visitor engagement metrics (Table 3). A similar approach could significantly enhance Chinatown Melbourne’s cultural appeal by curating mobile experiences that map historical routes, highlight landmarks, and guide visitors to hidden gems within the precinct.

Given Chinatown’s central location within the Hoddle Grid, pedestrian data could also inform infrastructure upgrades, such as installing wayfinding signage or expanding pedestrian pathways. However, a current limitation is the general nature of foot traffic data, which may not capture heritage-specific visitors. Addressing this by placing sensors near entry points and cultural sites would enable more targeted data collection. Additionally, combining these quantitative data with qualitative visitor feedback, as done in the Bordeaux and Dubrovnik projects, would provide a more comprehensive view of visitor experiences and preferences. By integrating these insights, Chinatown Melbourne can create a vibrant and culturally significant precinct that responds to both heritage preservation and contemporary urban needs.

4.2.3. Microclimate Data

Melbourne City currently employs a network of sensors to collect microclimate data, updated every fifteen minutes. These sensors monitor ambient air temperature, relative humidity, atmospheric pressure, wind speed and direction, gust wind speed, particulate matter 2.5 and 10, and noise levels. However, a key limitation for Chinatown Melbourne is that the nearest sensor is two blocks away and does not accurately reflect the microclimate of the enclave (Figure 3).

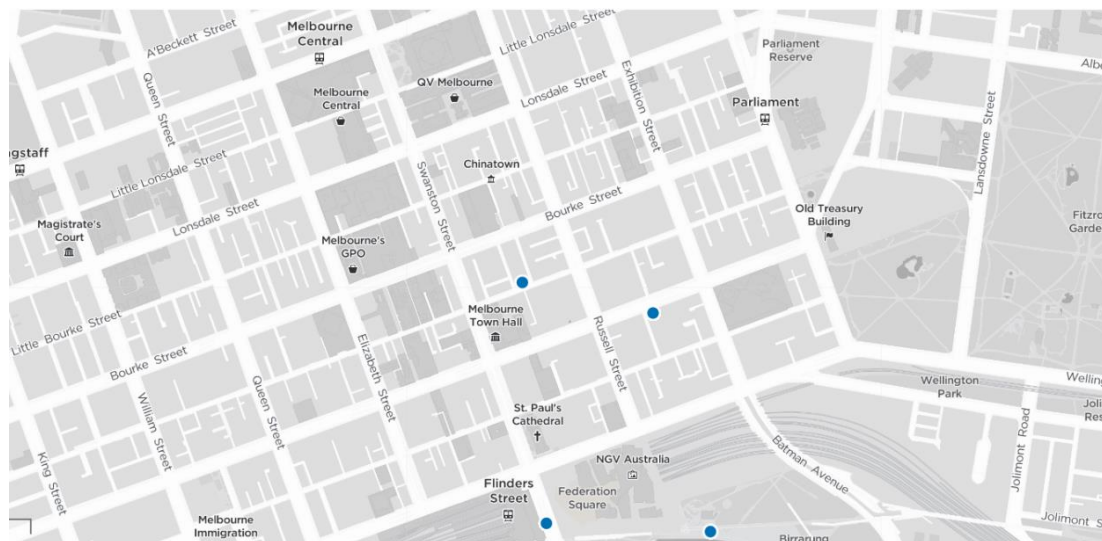


Figure 3. Microclimate sensor locations near Chinatown Melbourne (source: open-access data platform by the City of Melbourne).

The following ECST best practices demonstrate advanced strategies in Smart Heritage leveraging microclimate data, including City Management and Organisation (Padua), Smart Port for Integrated Urban Management (Aalborg), Smart Gateway for Smart Solutions and Solving Challenges (Cork), The Integrated Connectivity System (Palermo), Smart Kalea Platform, Data for City Management (San Sebastián), Smart Stations Project (Antalya), and Innovation in Mobility (San Sebastián). These projects focus on urban planning, city management, and outdoor events, and they use microclimate insights to enhance activity planning, infrastructure, and service implementation. While current studies predominantly focus on urban management phases involving data collection and processing, recommendations include implementing microclimate sensors within the precinct to gather data for future sustainable urban heritage planning. A fully integrated Smart Heritage precinct should gather and process data and then respond with informed decision making, making microclimate data pivotal for the precinct's environmental sustainability. Beyond ECST, existing studies explore smart heating, cooling, shading, and acoustic devices, offering future avenues for Smart Heritage research and application.

The best practices selected from other cities can be adapted to address challenges in Chinatown Melbourne, such as data-driven urban management, pedestrian safety, and environmental monitoring. For instance, the Smart Kalea Platform in San Sebastián is a smart urban project that enhances energy efficiency in commercial and residential areas using smart meters, renewable energy solutions, and monitoring systems. While originally developed in a different urban context, this project's strategies, such as energy consumption data, water usage analysis, and renewable energy adoption, can be adapted to improve resource efficiency in Chinatown Melbourne. Additionally, San Sebastián's integration of microclimate data to monitor pedestrian and vehicle flows is particularly relevant to Chinatown's need for better management of pedestrian density and parking congestion.

The relevance of these best practices lies in their adaptability to Chinatown's compact urban form, high visitor turnover, and unique cultural landscape. Incorporating San Sebastián's Smart Kalea Platform approach could help Chinatown implement smart energy management and microclimate monitoring systems, supporting sustainability and operational efficiency. Adopting these advanced strategies would not only enhance the precinct's resilience but also position it as a forward-thinking heritage site that integrates global Smart Heritage practices in a local context. This would ensure Chinatown's continued growth as a vibrant, culturally significant destination while benefiting from sustainable, data-driven urban management.

4.2.4. Dwelling Functionalities Data and Building Information Data

Currently, the City of Melbourne provides data on residential dwellings updated annually, based on the from the City of Melbourne's property rates database. This dataset categorises residential apartments, houses/townhouses, and student accommodations using a simplified classification schema. However, it does not extend to other functionalities. Figure 4 below records residential dwelling data, consistent with a previous study by Geng et al. (2022) using field observations [3]. Similarly, building information is available through the Census of Land Use and Employment (CLUE) dataset, covering the years 2002 to 2022, though updates for 2023 and 2024 are not yet included. This dataset includes building attributes such as location, construction year, refurbishment year, number of above-ground floors, predominant space use, bicycle/shower facilities, and accessibility features, although though accessibility data are primarily for internal City of Melbourne use. Few ECST projects directly address dwelling functionalities in their outlines, as the focus is primarily on heritage and cultural usage with tourism as a backdrop. However, some ECST best projects integrate urban and municipal services, particularly in tourism cities. Geng et al. (2023) notes that prior to 2023, most ECST projects were at a heritage site scale rather than city-wide implementations [3]. A shift towards city-wide implementation is evident in the 2023 and 2024 ECST best practices. This study suggests that dwelling functionality data could be effectively utilised in city-scale heritage projects or urban heritage precincts where

the distinction between heritage sites and urban settings is blurred. Sample best practices such as the Integrated Connectivity System (Palermo), Safety Circle Project (Antalya), Innovative Digital Municipal Solutions (Tetovo), Zagreb Smart City Hub (Zagreb), A Smart City Vocation (Palermo), Lviv IT Cluster (Lviv), and Smart Stations Project (Antalya) involve aspects of urban planning, Smart City initiatives, city management, and innovation in municipal services. Dwelling functionality data can provide insights into housing conditions, occupancy rates, and residential needs, contributing to more effective planning and resource allocation. Although current best practices do not fully utilise this potential, field observations indicate that Chinatown Melbourne predominantly consists of dwellings used for restaurants or retail, potentially leading to an identity crisis as an urban heritage precinct [4,5,59–61]. Open-access dwelling functionality data could accurately record dwelling functionalities to assist in re-vitalising the precinct's identity.

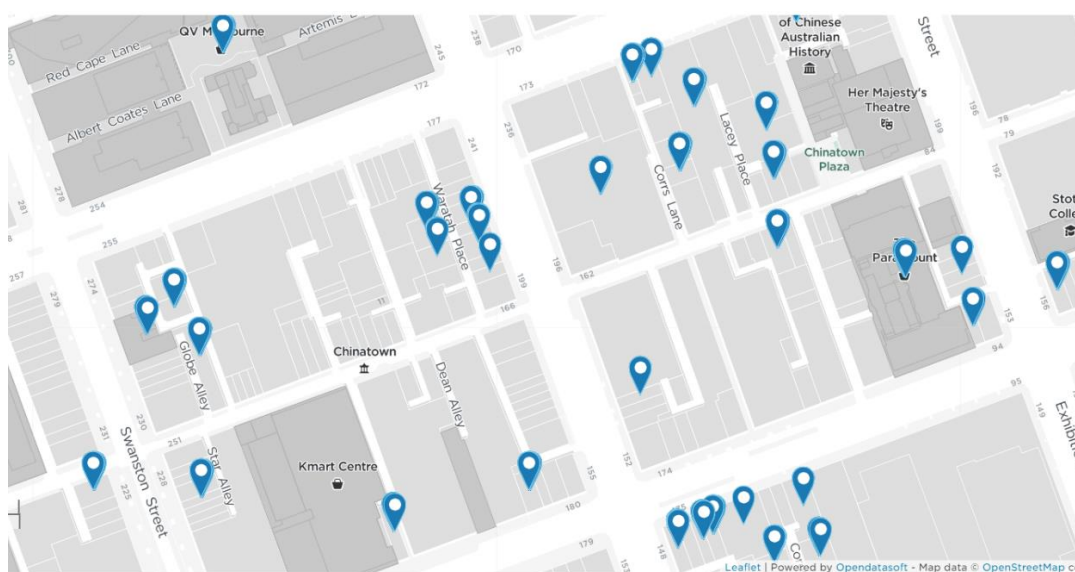


Figure 4. Residential dwelling locations in Chinatown Melbourne (source: open-access data platform by the City of Melbourne).

Using residential dwelling data presents an opportunity to enhance the urban heritage management of Chinatown Melbourne by providing insights into housing conditions, occupancy rates, and functional use patterns. Currently, the data collected by the City of Melbourne focus primarily on categorising residential types, without accounting for mixed-use developments or changes in property usage over time. Drawing on ECST best practices, such as the Integrated Connectivity System in Palermo and the Zagreb Smart City Hub in Croatia, a more comprehensive approach to data collection could better support urban planning strategies that balance residential needs with heritage preservation. The Zagreb Smart City Hub, for example, integrates digital infrastructure, including high-speed broadband and smart sensors, to gather spatial and dwelling data, monitor urban services, and support environmental management. Adapting this model in Chinatown Melbourne would enable more precise tracking of property use changes, particularly in residential spaces repurposed for commercial activity, providing a clearer understanding of how these shifts impact the precinct's heritage value.

Integrating dwelling functionality data into broader Smart City initiatives could also improve resource allocation and infrastructure planning in Chinatown Melbourne. Projects like the Safety Circle Project (Antalya) and Innovative Digital Municipal Solutions (Tetovo) show the potential for combining residential data with urban datasets to address safety, accessibility, and community wellbeing. Similarly, for Chinatown Melbourne, a more detailed understanding of residential dynamics could guide policies aimed at revitalising the precinct's heritage identity, ensuring that shifts in dwelling use do not detract from its

cultural significance. By capturing a more nuanced picture of property use and residential patterns, the City of Melbourne can make urban planning decisions that align with both the preservation of Chinatown's heritage and the needs of its residents. This would create a sustainable model for managing heritage precincts, bridging the gap between historical conservation and modern urban development.

4.2.5. Historic 3D Model of the Precinct Data

Based on Mahlstedt's 1895 image, a member of the City Council initiates a workflow to generate historic 3D models of Melbourne using an FME workbench to create 3D tiles comprising surface; Mahlstedt image; and extruded historic building footprints, including Chinatown Melbourne. Currently, these datasets and models are not publicly accessible, remaining in the documentation and digitisation stages (Figure 5). From the ECST, best practices engage in 3D modelling with AR and VR experiences, such as AR, VR, and 3D Reconstruction of the Alcazar of Seville (Seville) and AR and VR Experiences (Copenhagen). There is a noticeable shift in focus from best practices prior to 2023 to those in 2023 and 2024, where heritage projects move beyond digitisation to emphasise AR and VR experiences.

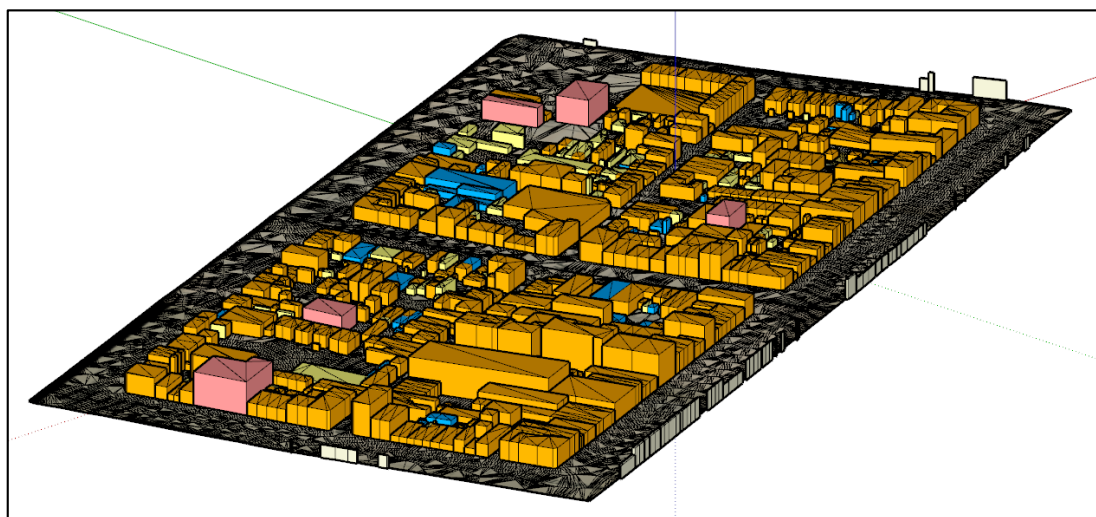


Figure 5. The 3D model data of Chinatown Melbourne based on Mahlstedt's historical 1895 map (source: city data, the City of Melbourne).

Some best practices indirectly involve 3D modelling, integrating concepts with 3D models, such as A Walkable City (Barcelos), Smart Tourist Trails (Malaga), Old Becomes New (Bordeaux), Rollindagando—Cultural Mapping of The Old Town (Genoa), Repositioning Málaga as the 'City of Museums' (Malaga), Generating Values for Tourists (Copenhagen), Metrominuto Tour and Maps (Genoa), and Smart App for Infos to The Historical UNESCO Park (Pafos). These projects span urban planning, tourism, cultural heritage, Smart City initiatives, and digital innovations where a 3D model of the precinct offers valuable spatial context and visualisation for planning, management, and enhanced visitor experiences [62]. This study notes that the current use of 3D modelling for exhibition and documentation purposes focuses on heritage digitisation, lacking autonomous applications. However, recent ECST best practices increasingly use 3D modelling with autonomous output capabilities focusing on historic data and current spatial massing and modelling. Beyond heritage documentation, 3D modelling data can be applied to ventilation and shading testing as well as integrated with other open-access datasets such as microclimate data. Future studies are encouraged to explore these applications further to enhance Smart Heritage transformations in Chinatown Melbourne and other urban heritage precincts.

The ongoing digitisation of Melbourne's historic 3D models, using the Mahlstedt 1895 image and FME workbench, marks an important step in digitally preserving the city's heritage. By generating 3D tiles that include surface data, historical imagery, and

extruded building footprints, the project offers a valuable spatial reference for the historical context of Chinatown. However, the current focus on documentation limits its potential, as these models are not yet accessible to the public and remain underutilised for broader heritage applications. Drawing from ECST best practices, such as the 3D Reconstruction of the Alcazar of Seville, which uses architectural and historical data to create immersive experiences, Chinatown's 3D modelling initiative could greatly benefit from expanding its scope.

Incorporating AR and VR technologies into Chinatown Melbourne's 3D modelling project would transform it from static documentation into an interactive experience. Visitors could virtually explore historic streetscapes and buildings, enhancing their connection to the precinct's heritage. Additionally, combining 3D models with other datasets, like microclimate data, could support innovative applications such as environmental simulations for shading and ventilation. By aligning with global best practices, Chinatown's heritage management could shift from a passive archival role to an active contributor to urban planning and public engagement. Moving beyond documentation to interactive and functional outputs would help Chinatown Melbourne leverage its historical assets to create a forward-thinking Smart Heritage precinct, balancing preservation with future development.

4.3. Data-Driven Approaches for Smart Heritage Implementation in Chinatown Melbourne

Building on insights from global best practices and local data analysis, Stage 3 synthesises these findings to develop data-driven strategies for Chinatown Melbourne's Smart Heritage initiatives, ensuring a tailored approach that addresses both cultural preservation and practical urban needs. To address the third research question, the study consolidates findings from previous stages by aligning available open-access data with relevant strategies for the City of Melbourne to support Smart Heritage implementations (Table 4). These findings are derived from case studies and the literature, as discussed in Section 4.2, where the matched case studies are detailed. In Chinatown Melbourne, on-street parking data enable real-time monitoring, facilitating traffic management systems that reduce congestion and improve accessibility, particularly during peak tourist periods. Efficient parking management will minimise disruptions to pedestrian areas, making the precinct more welcoming to visitors. Pedestrian counting data provide valuable insights into visitor movement patterns. These data can guide the development of infrastructure like walkways and signage, improving foot traffic flow while ensuring key cultural sites remain accessible without overcrowding. Managing visitor movement effectively enhances the overall visitor experience. Microclimate data help maintain a comfortable environment by monitoring temperature, humidity, and air quality. This information can inform urban planning decisions, such as where to place shading or seating, ensuring the precinct remains comfortable for visitors throughout the year. The 3D historical models offer opportunities to create immersive educational experiences. These models can be used in AR/VR applications, allowing visitors to explore Chinatown's architectural history interactively and enhancing the precinct's educational and cultural offerings. Dwelling functionality data identify underutilised spaces that can be repurposed for cultural activities like exhibitions or community hubs. This revitalisation fosters greater cultural engagement and strengthens Chinatown's identity as a dynamic cultural and Smart Heritage destination. The strategic use of these datasets will optimise visitor access, improve sustainability, enhance cultural engagement, and revitalise underused spaces, all contributing to Chinatown Melbourne's role as a vibrant cultural and Smart Heritage precinct.

Table 4. Summary of Smart Heritage strategies and expected outcomes using open-access data in Chinatown Melbourne.

Available Open-Access Data Type	Strategy for Chinatown Melbourne as a Smart Heritage Precinct	Potential Outcomes
On-Street Parking Data	Implement real-time parking availability and traffic control systems using smart sensors	Reduced congestion, improved visitor access, enhanced traffic efficiency
Pedestrian Counting Data	Improve foot traffic management and develop infrastructure (e.g., walkways, signage) based on crowd flow data	Improved visitor experience, smoother movement within the precinct, targeted infrastructure development
Microclimate Data	Use environmental monitoring (e.g., temperature, humidity) to inform sustainable urban planning and comfort measures	Enhanced sustainability, better visitor comfort, climate-adaptive infrastructure
Dwelling Functionality Data	Repurpose underutilised spaces for cultural and community activities based on occupancy and usage data	Revitalised precinct identity, increased cultural engagement, flexible space use for events and exhibitions
3D Historical Models	Create AR/VR experiences showcasing Chinatown's historical architecture for educational and tourism purposes	Interactive visitor experiences, strengthened heritage education, immersive heritage interpretation

5. Discussion

This discussion examines how the findings from the results integrate ECST Smart Heritage best practices with local data insights to inform effective strategies for Chinatown Melbourne and their further implications. It highlights the challenges and opportunities for enhancing cultural engagement and sustainability while proposing actionable approaches to revitalise the precinct's identity and address key challenges.

5.1. ECST Best Practices—Current Trends

A prominent trend in recent ECST best practices, as concluded from this study and Geng et al. (2023) on previous best practices, is the integration of smart technologies. Recent ECST best practices emphasise moving beyond mere digitisation to incorporate advanced technologies such as AI, IoT, and big data. These technologies enable autonomous capabilities that enhance the management and conservation of cultural heritage sites. Current frontier research explores how AI can enhance the overall experience and management of heritage sites. From an urban heritage perspective, IoT and AI can effectively link heritage sites with the surrounding city context. Another notable shift is the emphasis on enhancing visitor experience and engagement through Smart Heritage interventions. ECST best practices increasingly focus on creating interactive and personalised experiences for visitors, leveraging AR, VR, and smart tourist trails to provide immersive heritage experiences.

Environmental sustainability remains critical in Smart Heritage best practices. Projects often integrate smart solutions for monitoring and managing environmental impacts, including smart traffic control systems, microclimate analysis, and energy-efficient technologies, utilising relevant open-access data. Aligned with findings from Geng et al. (2023), there is a clear trend towards integrating Smart Heritage solutions at the city scale, moving beyond individual heritage sites or stand-alone applications. Many projects inherit Smart City initiatives, integrating heritage projects with the surrounding city's needs and environment, encompassing urban planning, mobility, and city management systems.

While European case studies like the 3D Reconstruction of the Alcazar of Seville and AR and VR Experiences in Copenhagen highlight large-scale smart heritage and tourism projects, Chinatown Melbourne's pilot project is a more localised effort with a different focus. The European projects pivot around advanced technologies and integrated datasets to provide immersive experiences aimed at attracting international tourists and promoting cultural tourism. In contrast, the Chinatown project focuses on resolving the precinct's identity crisis through digital curation and community-oriented heritage management

rather than tourism. This difference in scope underscores a gap in Chinatown's current heritage strategy—there is significant potential to expand the use of smart technologies beyond local interpretation to include elements of smart tourism.

Expanding the Chinatown Melbourne project to incorporate components of successful European models could greatly enhance the precinct's appeal. By integrating 3D visualisations with AR-based historical narratives, the project could offer more immersive and educational experiences for visitors [63,64]. This would not only attract a broader audience but also align Chinatown with global best practices in smart heritage and tourism. Additionally, leveraging smart technologies for personalised visitor experiences and combining them with data-driven environmental sustainability measures could transform Chinatown into a model for integrating local heritage with cutting-edge smart city solutions. This expansion would bridge the current gap between community-oriented heritage management and the broader potential for smart tourism, positioning Chinatown as both a local cultural hub and a forward-thinking smart heritage precinct.

5.2. Possible Smart Heritage Solutions for Chinatown Melbourne

Chinatown Melbourne, one of Australia's oldest ethnic enclaves, offers a unique opportunity to showcase its rich history and cultural significance through advanced digital and smart technologies. The application of data-driven Smart Heritage strategies not only addresses logistical issues such as traffic management but also provides a pathway for revitalising Chinatown's cultural identity. By repurposing underutilised spaces for community activities, as highlighted in Section 4.3, the precinct can strengthen its position as a cultural hub, fostering deeper engagement with both locals and visitors. As highlighted in the results, the precinct's identity crisis, driven by a shift away from its residential and community roots towards a more commercial focus, presents both challenges and opportunities. To address this, use of smart technologies and digital platforms could play a critical role in recontextualising the precinct's cultural significance [65]. Utilising 3D modelling to enhance digital curation and interpretation could effectively attract more visitors and educate the public about its heritage significance. However, this is linked to the precinct's identity issue, where culturally used dwellings are limited. Currently, the precinct has only one museum, with most visitors attracted to the dining scene. Implementing interactive heritage trails and AR-based historical narratives offers not only an opportunity to educate visitors but also to transform Chinatown into a living museum [66]. By integrating open-access data with urban planning strategies, Chinatown Melbourne can achieve a dual objective of rejuvenating the precinct while preserving its cultural heritage. The alignment of real-time data with urban sustainability efforts, as explored in Section 4.3, demonstrates how smart technologies can support both immediate operational improvements and long-term cultural preservation. By creating experiences that emphasise both the tangible and intangible heritage, such as the lived experiences of early Chinese migrants, Chinatown could address the identity crisis by reconnecting with its cultural roots. Moreover, integrating these digital tools with existing cultural events like the Moon Lantern Festival could foster a deeper connection between the community and its history, expanding the precinct's appeal beyond dining to a broader cultural experience [5].

As noted in the results by Geng et al. (2023), the Chinese community no longer resides in the precinct, primarily comprising business owners serving diverse cultural backgrounds, contributing to the precinct's identity crisis. Increasing cultural attractions could enhance the precinct's tourist appeal, while open-access data on dwelling functionalities could facilitate decision-making processes. While the results identified the potential of using this data to develop new cultural attractions, the discussion must consider how these initiatives can be tied to broader urban planning and cultural preservation goals. For instance, transforming underutilised commercial spaces into pop-up museums, community centres, or cultural galleries would not only revitalise the area but also create spaces for storytelling and cultural exchange [67,68]. These projects, integrated with smart technologies like AI-

guided tours or interactive displays, could become anchors for re-establishing Chinatown as a place of cultural significance rather than purely a commercial zone [69].

Another area for improvement through open-access data and Smart interventions is the precinct's traffic. Given its unique spatial layout with narrow streets and laneways within the cityscape, Chinatown Melbourne could significantly benefit from smart parking and traffic control systems. Beyond alleviating congestion, smart traffic solutions could help preserve the precinct's vibrant atmosphere by making it more accessible and safer for pedestrians. Drawing on global best practices, such as those seen in Málaga and Athens, implementing IoT sensors and real-time traffic management could also support Chinatown's heritage goals by guiding visitors through key historical landmarks and less congested pathways, ensuring that visitors engage with the precinct's cultural heritage as part of their overall experience [35]. These systems could alleviate long-standing traffic and parking issues while preserving the precinct's vibrant atmosphere, as outlined in the Chinatown Action Plan 1985, effectively dispersing foot traffic and highlighting lesser-known cultural landmarks.

5.3. Further Implications

The successful implementation of digital and smart heritage solutions in Chinatown Melbourne hinges on sensitivity to the precinct's unique socio-cultural dynamics and ensuring broader community concerns regarding heritage authenticity are addressed [70,71]. These technologies, such as 3D modelling, AR, VR, AI, and autonomous data analytics, must be deployed in a participatory framework that prioritises the agency of the local community [72,73]. Without this involvement, there is a risk of commodifying or oversimplifying the precinct's cultural identity. Collaborating with local stakeholders, business owners, cultural organisations, and the wider Chinese Australian community is crucial to ensure that these digital projects resonate authentically and contribute to a deeper understanding of the precinct's heritage [5].

A Community Heritage Advisory Group could serve as a structured mechanism for incorporating diverse community perspectives into the design and execution of digital heritage projects. This group would play a critical role in curating content, advising on interpretation strategies, and ensuring alignment between new technologies and existing cultural narratives [74]. Through co-design workshops and focus groups, community members could contribute oral histories, personal narratives, and artefacts for inclusion in 3D reconstructions or AR heritage trails, reframing the precinct's identity to reflect the lived experiences of Chinese Australians across generations [74,75]. Partnerships with educational institutions and cultural organisations could amplify the impact of these digital heritage initiatives. Educational programs using digital tools like VR and 3D modelling could engage students and visitors alike with Chinatown's complex history, offering interactive learning experiences [60]. For example, students could digitally reconstruct historic buildings, learning both architectural techniques and the socio-cultural dynamics that shaped the precinct. A Living Heritage Archive could further support this by collecting and digitising community-contributed materials with GIS, creating an evolving resource that reflects Chinatown's diverse narratives [76,77]. This archive could be an asset for future research, heritage programming, and policy development.

In addition to these educational strategies, public engagement could be enhanced through interactive digital kiosks installed throughout the precinct. These kiosks could disseminate historical information while allowing visitors to leave reflections and engage dynamically with the content [78]. Real-time feedback systems would offer valuable insights into visitor interests, helping to shape future heritage programming and bridging the gap between static heritage presentations and community-driven narratives [79]. Data-driven urban planning is also essential for balancing heritage conservation with commercial and infrastructural needs. Open-access data could inform adaptive reuse strategies for underutilised spaces, revitalising the precinct with new cultural centres, creative hubs, or community spaces that reflect Chinatown's evolving identity. Additionally, pedestrian

flow and mobility data could improve walkability and accessibility, ensuring the precinct remains inclusive and safe for all visitors [80]. These data-driven interventions would not only address functional challenges but also enhance Chinatown's social and cultural vitality, reinforcing its role as a living, dynamic heritage precinct. Ultimately, these strategies, grounded in community engagement, inclusive representation, and data-driven urban planning, would position Chinatown Melbourne as a leading example of smart heritage interventions that go beyond preservation. By transforming the precinct into an interactive, community-driven space, these initiatives would ensure that heritage is actively experienced, interpreted, and reshaped for future generations. This integrated approach would foster cultural resilience, promote social cohesion, and align Chinatown Melbourne with broader trends in sustainable urban development.

6. Conclusions

This study examines the available data for Chinatown Melbourne, largely open-access, and explores its application within the Smart Heritage context. By using Chinatown Melbourne as a case study, the findings provide an overview of key data resources, on-street parking, pedestrian counting, microclimate, dwelling functionalities, and 3D models, and they connect them with relevant ECST best practices. This study identified several key strategies to transition Chinatown to a Smart Heritage precinct and improve visitor engagement, such as smart traffic control systems, AR/VR integration for heritage curation and education, and data-driven urban management. Notably, trends in recent ECST projects highlight a shift from digital to autonomous technologies and from small-scale to city-wide implementations. By aligning these Smart Heritage best practices with Chinatown Melbourne's unique data and urban characteristics, the highlighted data-driven strategies, such as real-time parking monitoring and pedestrian flow management, are crucial for revitalising the precinct and enhancing the visitor experience.

Furthermore, the findings directly address the research questions by demonstrating how open-access data can be leveraged to implement Smart Heritage strategies, promote the revitalisation of underutilised spaces, and enhance cultural engagement in Chinatown Melbourne. Engaging local stakeholders and the Chinese Australian community is vital for maintaining the precinct's cultural integrity and ensuring that digital heritage solutions reflect authentic cultural narratives.

While this study provides valuable insights, certain limitations should be acknowledged. The reliance on open-access datasets meant that some aspects of heritage management, particularly those requiring more granular spatial data, could not be fully explored. Additionally, as the study focused primarily on Chinatown Melbourne, generalising these findings to other heritage sites will require further comparative research. Addressing these limitations in future studies through expanded datasets, additional global case studies, and increased institutional collaboration could significantly enhance the scope and applicability of smart heritage strategies. Future research could focus on integrating autonomous technologies and expanding data-driven strategies to other urban heritage precincts, as well as understanding the role of stakeholders and investigating funding.

This study identified several current constraints for the precinct's use of open-access data, including the lack of localised microclimate sensors and the need for better categorisation of pedestrian data. A collaborative approach will be essential for addressing these challenges. Based on this study's findings that demystify Smart Heritage through practical applications and the use of open-access data, key recommendations for future research include:

- Comparing Smart Heritage projects from the ECST with other global initiatives.
- Elucidating potential Smart Heritage applications for other urban heritage precincts using the transferable methodology from this study.
- Discussing the roles of stakeholders in Smart Heritage applications.
- Analysing funding mechanisms for Smart Heritage transformations.

Overall, this study offers valuable insights for researchers and policymakers, providing a framework for linking open-access data with practical Smart Heritage applications. The strategies highlighted in the results, derived from the integration of specific datasets, present actionable solutions that can support sustainable, community-driven heritage management in Chinatown Melbourne and serve as a model for other urban precincts. By connecting the findings across its progressive stages, this study demonstrates how global best practices inform local data strategies and ultimately shape actionable strategies for Chinatown Melbourne, reinforcing the logical progression from theory to practice in Smart Heritage implementation.

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Appendix A

Table A1. Best practices in the 2023 and 2024 ECST under the categories of ‘cultural heritage and creativity’ and ‘digitalisation’ relevant to Smart Heritage.

Best Practice Category in the ECST 2024	Subcategory	Project
Cultural Heritage and Creativity		
Cultural Heritage Usage for New Creativity	Promotion Of Creative Industries Use Of New Technologies	Chroma Light Show, Amiens The ‘Lighting for Genoa’ Project, Genoa
	Creating New Cultural Spaces	A Walkable City, Barcelos
	Non-Specified Subcategory Prior 2023	A Glimpse into A Genius’ Mind, Copenhagen A Cultural Platform for All, Copenhagen Reinventing Sauna Culture, Helsinki Repositioning Málaga as the ‘City of Museums’, Malaga Smart Tourist Trails, Malaga
Creating Communal Infrastructures (2023 specific)	Non-Specified Subcategory Prior 2023	Experiencing Athens like a Local, Athens Public Library, Helsinki
Cultural Heritage Usage for New Creativity (2023 specific)	Non-Specified Subcategory Prior 2023	Old Becomes New, Bordeaux Generating Values for Tourists, Copenhagen A Chatbot Giving Guided Tours, Copenhagen The Festival of Lights, Lyon

Table A1. Cont.

Best Practice Category in the ECST 2024	Subcategory	Project
Digitalisation	Digital Innovation in City Guides	Technology-Enabled Tourist Information, Cork The Bremerhaven guide App, Bremerhaven The Visitgenoa App, Genoa 'Gdynia City Guide' Website and App as a Comprehensive Guide, Gdynia 'Tomis' Tablets as An Information Panel for Public Use, Matosinhos Making Suggestions to Visitors Via 'TpnP Tomi Go Matosinhos' App, Matosinhos
	Facilitating Information for Specific Groups	Digital Innovation for an Enhanced Tourism Experience, Odense Digital Applications, Parma Our Destination Online, Helsingborg Detect Aarhus App, Aarhus Metrominuto Tour and Maps, Genoa Rollindagando (Cultural Mapping of The Old Town), Genoa Smart App for Infos to The Historical Unesco Park, Pafos World Heritage App and Portal, Seville
Collecting Information for Smart Management	Augmented Reality in Tourism	Augmented Reality of Zeugma Ancient City, Gaziantep Augmented Reality Routes, Gijón 'Tourist Lublin' App and AR, Lublin Myth Of Aphrodite App and AR Experience, Pafos AR, VR, and 3D Reconstruction of the Alcazar of Seville, Seville
	Open Data for Improving Tourism	Gijón Open Portal, Gijón Understanding Local Sentiment Toward Tourism, Dublin 'Istanbul Is Yours' App, Istanbul
Collecting Information for Smart Management	Smart Urban Management	Digital Strategy 2017–2030, Thessaloniki City Management and Organisation, Padua Smart Port for Integrated Urban Management, Aalborg Smart Gateway for Smart Solutions and Solving Challenges, Cork The Integrated Connectivity System, Palermo Smart Kalea Platform, Data for City Management, San Sebastián
	Public Safety Through Digital Solutions	Safety Circle Project, Antalya
Collecting Information for Smart Management	Digital Municipal Solutions	Innovative Digital Municipal Solutions, Tetovo
	Open Data for Improving Tourism	Destination Hub. Ruhr, Essen Fiware, Seville The Realisation of the Taranto Ecosystem Platform, Taranto Zagreb Smart City Hub, Zagreb
Collecting Information for Smart Management	AI In Smart Tourism	'Virtual Clerk' as an Artificial Intelligence Tool, Gdynia
	Digital Solutions in Business	Digital Training for Private Businesses, San Sebastián:
Collecting Information for Smart Management	Non-Specified Subcategory Prior 2023	Park Smarter, Athens Park Smarter, Dubrovnik Data Collection and Sharing for A Better Tourism Experience, Dubrovnik

Table A1. Cont.

Best Practice Category in the ECST 2024	Subcategory	Project
Transformation into Digital Knowledge Sharing	Digital Access to Information	'Trafiku Urban' Mobile App, Prishtina Promotion of Digital Applications, Gaziantep Culture in One Click, Saint-Denis A Smart City Vocation, Palermo
	Promotion Of Digital Innovations	Lviv It Cluster, Lviv Klaipeda University, Klaipeda
	Digitalisation In Cultural Spaces	'City Memory Museum', Eskisehir
	Digital Culture and History Experience	Discovery Trails City App, Dublin Essen 1887, Essen Technology Developments, Helsingborg
Innovative Mobility through Digitalisation	Smart Benches	City-wide Free Wifi, Iasi
	Local Community Engagement	'Engage Skopje' Platform, Skopje
	Knowledge And Technological Capabilities	Innovation In Mobility, San Sebastián
	Autonomous Driving Public Transport	First Autonomous Bus in Denmark, Aalborg
	Smart Bus Stops	Smart Stations Project, Antalya
	Smart Parking	Smart Parking System, Pafos
Physical and Psychological Accessibility Through Innovation	Non-Specified Subcategory Prior 2023	Apps to Experience History or Sights, Athens, Bordeaux, Copenhagen AR and VR Experiences, Copenhagen Virtual Reality Programme, Helsinki # Myhelsinki, Helsinki Understanding Visitors via Elaborate Data, Lyon, Malaga Smart Traffic Control for Tourists and Locals, Malaga

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