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Smart Heritage for Urban Sustainability: A Review of Current Definitions and Future Developments

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ABSTRACT

Smart heritage is still novel in heritage discourse, with a few relevant review articles. In this regard, a specific interpretation of smart architectural heritage and a framework for instructing its development is lacking. This article reviews the literature on smart heritage in sustainable development to fill the knowledge gap. As a methodology for this study, the integrative review approach and thematic analysis are adopted to review references located at the crossroads of historic, smart, and sustainable disciplines. The review and interpretation draw on literature from relevant fields to understand implementations, current states, and support to interpret smart heritage. Review outcomes indicate that smart heritage is becoming dynamic as technologies are increasingly applied to more detailed heritage branches. This article lists the factors that heritage should possess to be defined as smart, and it provides a framework that might be followed to achieve the aims of this discourse by stating that smart heritage discussions are relevant to smart cities, as they may have a mutual effect and interact to promote each other.

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1. Introduction

Topics around sustainable development have been evolving for more than 30 years. Environmental concerns, energy decisions, social issues, and other aspects of urban development should be integrated (Rogers et al., 2012). With the involvement of smart concepts in sustainable development, environmental, sociological, and economic concerns are increasingly considered in the quest for a higher standard of living (Deakin, 2001). These factors are linked, and they are all necessary for individual and social well-being. In a specific system, such as a building, "smart" refers to an entity with sophisticated control systems and technologies that enable interconnected operability and the capacity to respond quickly to external and internal communications (Pipattanasomporn et al., 2009). Many studies have discussed smart concepts (e.g., smart grid, smart buildings, and smart cities) and their interactions.

Smart grid ideas advocate using modern information and communication technology (ICT) infrastructure to enhance grid (and grid-

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edge, for example, consumer) monitoring and control and communication between them (Good et al., 2017). Definitions of smart buildings have been proposed and constantly evolved since 1980, and a structure's smartness is defined as a space with complete control over its surroundings (Wong et al., 2005). Frequent discussions exist among researchers, industry experts, communities, and higher government-level officials concerning smart buildings and smart cities since buildings and infrastructure must be developed and run in line with smart city features (Apanaviciene et al., 2020). Irrespective of what tools and applications are involved, the smart city definition is inclusive enough to cover all important initiatives. As an interdisciplinary topic, it must face increasing problems from various urban dimensions (Dameri & Rosenthal-Sabroux, 2014). The term "smart city" refers to using various information technologies or innovative concepts to connect and integrate urban systems and services to improve resource utilisation efficiency, optimise urban management and sources, and improve citizens' quality of life (Guo et al., 2016). A smart city connects various urban infrastructures to achieve urban intelligence (Harrison et al., 2010). This topic is a cutting-edge area for theoretical study and actual applications. Further research into smart cities is still developing (Dameri & Rosenthal-Sabroux, 2014).

Based on smart city research, new academic and industrial domains are emerging that mix technology and services, including policy discussions from other disciplines (Lim et al., 2021). However, understanding and describing smart cities from several viewpoints is difficult. Given the extensive use of this idea in various fields (for example, urban planning and administration), future studies should discuss smart city initiatives in more detail. Researchers agree that it is critical to interact with the past while considering the future (Sandford, 2019). Developments in heritage smartness are still novel, and some researchers have contributed to comprehensive heritage management and conservation through the digital domain. However, there are only a few review articles on smart heritage and sustainable development that exhibits lag in understanding and developing strategies for smart architectural heritage.

This article reviews literature relevant to smart heritage with a sustainable background. It aims to offer new insights into the architectural domain to develop a framework guiding implementations and applications. This paper does not review all academic publications on the topic but integrates views to construct novel interpretations. Section 2 describes the review methodology, including data collection and analysis methods. In Section 3, a review of smart heritage is conducted corresponding to different features. Section 4 categorises the key outcomes from selected publications and discusses the contributions of this review. Likewise, Section 5 presents the concluding remarks.

2. Methods and materials

A literature review is a method of gathering and analysing previous studies (Baumeister & Leary, 1997; Snyder, 2019; Tranfield et al., 2003). The literature associated with smart heritage covers various disciplines, which requires a creative data collection method. According to Snyder (2019), the integrative review approach can be adopted to understand smart heritage development. The authors reviewed literature from cultural heritage to different heritages extending into semantics, such as heritage monitoring, management, presentation, digitisation, and visualisation.

The article selection procedure cited by Tan et al. (2021) is specialised to correspond to the research aim of this study, and the review workflow is shown in Figure 1. Keyword searches in Science Direct and Scopus for "Smart Heritage", "Smart Cultural Heritage", and "Sustainability" support this review. In addition, highly relevant paper insights from selected articles are reviewed. This study untangles and structures pre-existing knowledge based on 44 highly relevant articles to smart heritage. The initial search included queries using a combination of "smart heritage" with "sustainability". Key concepts in cultural heritage are reviewed at the start to support keyword identification and narrow down the research scope. The keywords "smart cultural heritage" and "sustainability" are then adopted to conduct a review of publications on heritage smartness and cultural heritage domains. Two rules are set to filter the target literature: (a) identify cultural heritage in tangible domains, which excludes literature from intangible cultural heritage and (b) adopt concepts of smartness to promote architectural heritage protection and sustainable development.

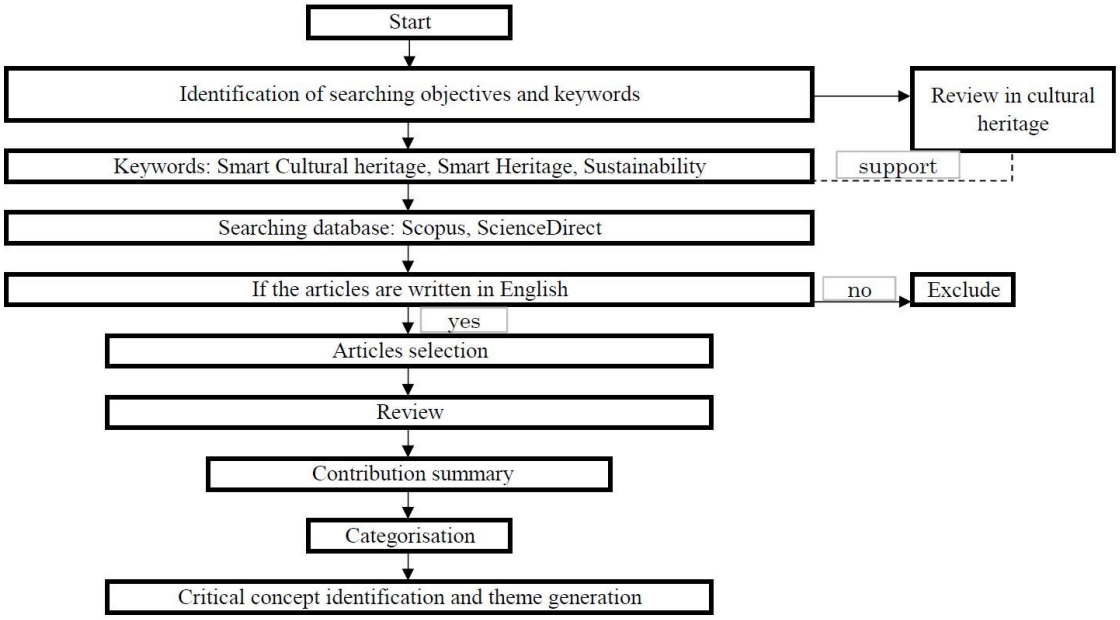

Figure 1. Article Selection Process.

Thematic analysis is used initially to identify common themes and ideas in data analysis. The authors use research topics and contributions from the selected articles to classify this review into three phases: 1) early discussion, 2) detailed discussion, and 3) particular discussions within specific discourse. Collected data were initially imported into Microsoft Excel to determine the general features of each document. After reviewing all selected publications, content analysis is conducted to identify the contributions from each study. The steps are as follows: one—summarising contributions based on the authors and years of publication; two—categorising them based on each contribution; and three—identifying critical concepts mentioned in the article and generating themes (Aktürk, 2022).

3. Results

3.1 Cultural heritage: key concepts

Cultural heritage includes tangible and intangible assets with historical, artistic, scientific, and cultural value (Ahmad, 2006; Vecco, 2010). It generally incorporates architectural works, works of monumental sculpture and paintings, archaeological sites, literary masterpieces, ethnological treasures, oral traditions, and unwritten languages (Bedate et al., 2004; Ferretti et al., 2014; Harvey, 1997). Cultural heritage is a crucial bridge linking humanity's past, present, and future. Over the years, its definition has been considered a dynamic category within constant social and cultural evolution (Li et al., 2020). In modern theory, cultural heritage definitions are constantly updated and reiterated; the whole is the result of continuous historical transformation and progress (Selim et al., 2022).

The UNESCO World Heritage 1972 Convention recognises cultural heritage monuments, groupings of structures and sites as having extraordinary historical, artistic, or scientific value (Cleere, 1996). Cultural heritage is essential to sustainable urban development in the New Urban Agenda. For instance, it can be used to protect and promote cultural infrastructures and sites, museums, indigenous cultures and languages, traditional knowledge, and arts in cities and human settlements (Agenda, 2016). Conflicts between preservation and development continue in urban development: traditional urban elements adapt to contemporary trends by incorporating tools and techniques enabling them to become smart (Koukopoulos et al., 2017). Heritage is an integral part of them.

3.2 Early research into smart heritage

When smart techniques are adopted in heritage fields, well-rounded and systematic conservation and management processes are involved. The exploration of new modes in different heritage discourses widens the knowledge of smart heritage. According to Adrian and Kurniawan (2020), INTACH Heritage Academy introduced smart

concepts into the heritage field in 2007 by addressing the challenges of cultural heritage conservation based on ICT.

Based on keyword searches in this study, discussions around smart heritage started in digital cultural heritage when Moustakas and Tzovaras (2010) proposed a virtual reality (VR) framework for heritage modelling and interactive simulation. In addition, Bearman (2011) mentioned smart objects in the museum discourse and highlighted that cutting-edge techniques help visitors have a more enjoyable visit. Tewfik and Mohamed (2013) suggested the use of smart aspects in heritage protection, and how integrating emerging construction and heritage environments needs to rely on measurable technologies and methods to meet the calls for sustainability.

Husain et al. (2013) indicated that integrated multidisciplinary information (for instance, geographic data) using smart tools not only documents the past and current status of heritage sites but also supports decision-making in the future. They considered how smartness may benefit sustainable development plans by reviewing and discussing the ways combined technology applications can potentially model a real web-based heritage scene. Thwaites (2013) discussed digital heritage and what occurs when heritage contents are digitised, pointing out that smart heritage and cultural futures refer to software that combines pictures and sound collected at heritage sites. Tools, such as animation and film, should be used to build complete hybrid virtual-reality environments as far as possible. Smart heritage research is promising because it aims to produce new experiences and ensures that the cultural future is intact (Thwaites, 2013).

Kenderdine (2013) used captured images combined with methods, such as narrative techniques, to create immersive panoramas of the Dunhuang Mogao cave site with rich details, which involved tourists and created an interactive scene. History and culture can be inherited. Chianese and Piccialli (2014) developed an Internet of Things (IoT) architecture that assisted the creation of a static cultural environment. Even though they did not directly mention smart heritage, they stated that modern technology, such as sensors, sought to turn cultural items into smart objects that could communicate with one another, visitors, and networks. This acquired characteristic is critical for cultural spaces' smartness. By adopting the IoT paradigm consisting of sensor nodes capable of transforming cultural spaces, stakeholders can develop strategies to support heritage smartness.

Other technology paths suggest a different direction for heritage smartness. Garau (2014) has discussed the current state of augmented reality (AR) in cultural heritage. A simulated case study in a historical neighbourhood proves that AR on mobile devices can dynamically offer smart and interactive solutions for the cultural heritage conservation scenario. Likewise, Chung et al. (2015) investigated how AR affects people's desire to visit historical places. Besides IoT, AR brings opportunities for heritage digitisation and visualisation (Selim et al., 2021), but smart heritage might consist of more than a single context or application. Chianese et al. (2015) used IoT to address complex links between transmitting historical knowledge and visitors' experiences in heritage environments through smart design. The development of smart objects supported the progress of this research with the aim of stimulating visitors' interest and enjoyment.

3.3 Technologies for developing smart heritage

Technologies play a crucial role in smart heritage development, highlighting the latter's potential to turn cultural institutions like heritage sites into current assets (Selim et al., 2022). Della Corte et al. (2017) described smart concepts being applied to museums and historical sites with smartness entailing ICT, as evidenced by deploying AR and 3D modelling during producing phases of cultural materials and using cloud environments during modelling and display phases (Della Corte et al., 2017). According to this study, smart heritage can be defined as an ICT-enabled virtual environment that satisfies the requirements of different stakeholders, such as online heritage touring, heritage protection, and sustainable cultural promotion. Borda and Bowen (2017) assessed cultural heritage in several cases across different countries using smart platforms and visualisation technologies. They found that the cities and cultural heritages' smartness needs require contextualised services, which can be made feasible by a shared set of fundamental technologies. With the implementation of smart advancements, those technologies are becoming pervasive and inextricably linked. Borda and Bowen

introduced visualisation technologies, such as simple infographics for 3D modelling and AR combined with technologies, such as IoT, which were applied to every project.

However, only some of the projects can be considered an achievement of smart heritage. For example, by aiming the devices' camera toward the object, an AR application named Skin & Bones created a virtual environment on real objects in the Smithsonian National Museum of Natural History in the United States. Visitors could use an app to test their natural history knowledge by participating in activities, such as identifying a bat by its characteristic sound. The app is available on mobile devices so that visitors can visit exhibitions virtually (Borda & Bowen, 2017). According to Chianese and Piccialli (2016), technological involvement is insufficient to deem a place smart because smartness must be developed by a collection of applications and services with integrated use of shared and created data. To that end, smart heritage should consider the extensive use of various cutting-edge technologies to achieve smartness across multiple aspects and serve stakeholders.

Riganti (2017) attempted to construct a smart heritage agenda for sustainable and inclusive communities with a model based on a previously established smart environment based on a geographic information system (GIS) to support decision-making in long-term cultural heritage management. Riganti's core point was that it is vital to comprehend the value placed on heritage products by diverse stakeholders, particularly local people, to develop full and deep management of cultural heritage. She further suggested that the environment can address most cultural preservation problems. Smart solutions, ranging from customised apps to sensors that provide real-time data, should be included in these categories: one—a user-friendly platform, two—an open heritage-mapping platform, and three—a platform with a basic set of features, such as high-definition 3D visualisation and real-time data (Riganti, 2017). Wang et al. (2018) employed a device-to-device (D2D) communication method based on 5G mobile networks to develop conservation and management networks to address issues of low transmission rates and expandability between IoT and wireless sensor network (WSN). Compared with the study by Qiu et al. (2015) and reviewed in the following section, Wang's strategy brings attention to museum digitisation and visualisation, using "smart cultural heritage" and emphasising how smart city and heritage disciplines strengthened their practical convergence and materialised smart heritage itself.

In the other domain, Khoshelham (2018) overviewed tools and strategies for collecting geographical data for modelling heritage buildings. According to the study, the concept of smart heritage could be described as achieving more rational decision-making in heritage building conservation with the involvement of spatial data and building information modelling (BIM). The initial stage in the documentation and preservation of historic structures is frequently digitised. However, it is an insufficient basis for making educated decisions about the usage and maintenance of heritage structures (Khoshelham, 2018). According to the author, complex tasks, for example, structural health monitoring and assessing environmental impacts like weathering, need to combine enough semantic information from geographical data in historical records and topological relationships into the BIM.

A historic BIM streamlines the ongoing documentation of all preservation and restoration efforts and the administration and interchange of building data. In contrast to Khoshelham (2018), Pocobelli et al. (2018) reviewed BIM applications in historic building conservation projects, using BIM technology to model building components as smart objects with numerical parameters defining the parametric information of the components (e.g., dimensions) and embedding other types of information, such as building materials and attributes. Pocobelli et al. (2018) emphasised giving smartness to architectural components and focusing more on the microscopic level. Anwar (2019) elaborated on how people–place linkages might be used to determine a cultural heritage area's smart implication. The smart city trend has led to using smart technology in heritage conservation. By employing tools such as photogrammetry, reality-based 3D documentation, and permanent digitisation, smart approaches of archiving and genuine digital surrogates represent two heritage restoration strategies. Social networking, 3D visualisation, and VR technologies are among the interactive features that deem the physicality of a heritage virtual. Virtual heritage has thus become a popular concept in culture and history preservation,

conservation, and interpretation (Abdelmonem et al., 2017).

Suwardhi et al. (2022) discussed the creation of a prototype for a multipurpose land management system for an urban cultural heritage region. The first step would be creating a 3D map for documentation of cultural heritage locations. This step would further support heritage protection. In addition, using laser scanners and photogrammetry, a model of a historic building could be visualised at various levels of detail and used in heritage building information modelling (HBIM) for building maintenance. 3D models can be saved as a 3D GIS, BIM, or a combination of the two (the so-called GeoBIM) based on data from the mapping process. Constructing a multipurpose land administration system prototype for the cultural heritage region contributed to Suwardhi's research, and this system included many advantages, including area planning, monitoring, and management.

Mitro et al. (2022) drew on cutting-edge IoT tools to empower smart heritage ideas with a proposed approach that was autonomous, efficient, and non-intrusive. Their article represented using advanced technology to bring smartness into heritage, using smart tag devices to achieve low power consumption and long operational life. The data collected deviated little from the weather station (Mitro et al., 2022). However, one of the disadvantages was that the smart tags functionality was limited to the sensor-monitor level. In terms of a comprehensive system, the smart tag needed to be considered further in terms of giving heritage a deeper level of smartness.

3.4 Smart heritage implementations and applications

Many scholars have focused on developing paths and serving scenarios of smart heritage. Qiu et al. (2015) proposed a novel service system named "one platform—three systems" to address challenges in archaeological site data analysis and site management operations. It consisted of an online-offline-onsite service system and a digital explanation system, also called a smart-heritage management system. The presented platform achieved bidirectional engagement between heritage site management units and tourists, with visitors able to benefit from explanation and illustration of the sites' cultural and economic values. Based on this study, smart heritage in the archaeological domain can be understood as a comprehensive system capable of operating and managing heritage data and providing heritage presentation.

Piccialli and Chianese (2018) attempted to recognise the connections between history and smart technology, characterising the smart cultural environment as a new idea that blends objects, sensors, services, and apps into cultural sites, such as museums, monuments, and exhibitions. Vassilakis et al. (2018) developed a smart method capable of achieving specific heritage displays from an enlarged cultural collection database controlled by users' data. Compared to Piccialli and Chianese, who highlighted the originality and connectivity of cultural objects, Vassilakis et al. focused on smart technologies, as they fulfil significant roles in heritage presentation and communication.

Ardito et al. (2018) offered a strategy for end-user development for integrating smart device services. Fourteen professional guides from various cultural heritage sites in Southern Italy were involved in this study. Using a visual composition paradigm, end-user approaches provided opportunities to customise systems for diverse users' situational demands. Balducci et al. (2020) considered visitors' interests and feelings by improving smart interactive experiences, focusing on an interactive paradigm based on IoT technologies for managers and operators to synchronise different smart objects into a specific environment to satisfy visitors' needs.

It is worth noting that Ardito et al. (2018) aimed to develop interactive methods in which end-users without programming abilities might have smart experiences through the interoperable management of smart objects. Some resources, such as smart objects or web services, were required for the smart experience, but Balducci et al. (2020) focused more on the visitors' interactive experiences. Heritage smartness should become a system aggregating advanced technological tools and satisfying the stakeholders. Therefore, holistic considerations in the technological level of platforms and serving objectives are crucial to developing a smart heritage. It is also a beneficial exploration of organically combining art, technology, and humanities. According to Lerario and Varasano (2020), smartness in architectural heritage should be regarded as a holistic approach that not only brings the systematic opportunity with

monitoring and protecting function into heritage but also links heritage with urban data processing, environmental monitoring, economic growth, and public services. Cultural heritage smartness is highly likely to affect the promotion of social cohesion and push innovation, especially when combined with smart city initiatives (Borda & Bowen, 2017).

Visan and Ciurea (2020) provided a functional system for the digital transformation of cultural heritage and actual procedures for realising virtual displays. Collaborations with IoT and mobile technologies are indispensable when looking to facilitate smart cultural heritage development. In parallel, digitalisation efforts efficiently disseminate key historical data sources and help to preserve the past. Digital cultural heritage is brought to life through innovative visual analysis, interpretation, and engagement methods.

Cultural factors influence the progression towards more sustainable options and acceptance and implementation of circular economy ideas (Stanojev & Gustafsson, 2021). Different urban development stakeholders notice clear economic factors in future sustainable development. Therefore, smartness in cultural heritage should not be neglected. According to Borda and Bowen (2017), integrating heritage and advanced technologies benefits the economy and culture by attracting more tourists, protecting heritage, and creating more jobs. Carrying out theoretical and practical innovation in heritage protection and management is vital to building a modern public cultural service system.

3.5 Smart heritage within smart cities

With a more detailed and profound discussion of smart heritage in different fields and layers, as the previous authors (Borda & Bowen, 2017; Sindhu & Reshmi, 2020) mentioned, heritage smartness is directly or indirectly affected by the development of smart cities, and these two concepts tend to be inseparable and are worth discussing together. Cultural heritage is an invaluable global resource, and its relevance to a smart city grows as it is integrated into the digital ecosystem, especially when considering urban history and civilisation in the construction of the system (Amato et al., 2013). Sindhu and Reshmi (2020) stated that cultural infrastructure, including notable heritage structures, is an essential feature of cities, which should be included in smart city programmes, and that smart city applications can help with heritage monitoring and maintenance.

Angelidou et al. (2017) discovered that cultural heritage management could be implemented through many smart city strategic areas, reflecting various points of view and supporting several aims. The authors found that smart city approaches could strategically underpin smartness. They added that considerations of specific tools and applications for meeting urban developing trends, such as liveability and sustainability, can support the objectives of cultural heritage preservation and promotion in the context of a smart city. Three years later, Angelidou and Stylianidis (2020) revisited the progress achieved, focusing on whether the inadequate substantiation of heritage in smart city policies mentioned in 2017 had been improved. Tarragona (Spain), Budapest (Hungary), and Karlsruhe (Germany) were smart city examples chosen in this study, which found that cultural heritage smartness was not addressed sufficiently within these smart city initiatives. Their conclusion can be regarded as an interpretation of smart heritage, highlighting adopting sensors and other advanced hardware and software as the way to achieve the following goals: one, improving visitors' experiences; two, raising public awareness of a specific cultural heritage; three, preserving cultural heritage; and four, better managing conditions and utilities in heritage sites. The importance of cultural heritage in smart urban initiatives is rising, driving the emergence of a trend that links cultural heritage with sustainable urban development.

Mar et al. (2018) introduced an application in which different stakeholders of historical sites could share a visit itinerary with detailed real-time information tailored to their interests. The authors committed themselves to extending a smart city idea into a Smart Historical City project (SHCity), which took on an unprecedented challenge of producing an open-source tool to connect urban heritage centres. The SHCity was characterised as a system that processes information from urban 3D maps and data from sensor networks to monitor various heritage sites. This study combined digital sensors with historical sites to collect data and made it accessible to management and tourists, presenting a great example of achieving smart heritage.

According to Allam and Newman (2018), smart cities often reflect the ICT industry, ignoring the cultural and historical characteristics that certain cities have inherited. Neve (2018) indicated that prevalent notions about the nature of cities' smartness, cultural heritage, and the popular topic of smart cities do not appear to be a good fit. Neve emphasised the critical need for multidisciplinary research projects examining the interrelationships between all city aspects. Placing heritage at the cities' core, smart heritage should be understood as a coevolving assemblage of the built environment and people. Heritage's smartness research is critical for sustainable urban development. Adrian and Kurniawan (2020) discussed whether smart heritage were relevant to cultural sustainability when smart city development became a hot topic in the 2000s. According to previous research (e.g., Chianese & Piccialli, 2014; Della Corte et al., 2017), as people moved toward an ICT-equipped smart era, INTACH developed solutions to support visitors' experiences, archaeological work, and management of cultural heritage based on shared interests and decisions that engaged people and experts and aimed at developing heritage conservation, management, archaeology, interpretation, and experience. However, Adrian and Kurniawan (2020) indicated that smart heritage was still novel and yet to be completely implemented in any city. The role of smart heritage development is to help in decision-making in cultural heritage protection and create new prospects for economic growth while satisfying the public need for knowing, researching, and preserving (Adrian & Kurniawan, 2020).

Brusaporci (2020) analysed tangible heritage definitions, discussed difficulties in heritage digitisation, and underlined new linkages between actual dimensions and digital heritage. As a vital element of cities, architectural heritage studies have exceeded mere modelling and visualisation. In contrast to previous outcomes developed by other scholars, Brusaporci did not regard smart heritage and smart cities as two entirely different concepts; instead, the smart city approach was directly adopted to process a multitude of inputs, stakeholders, and outputs in the urban heritage context. The author employed a comprehensive smart city approach to defining smart heritage, which included seamless interactions between smart technology and heritage in various ways. Brusaporci mentioned that the ICT's involvement in cultural heritage promotes a cultural shift, resulting in a sustainable inheritance of culture and history in smart city contexts. With AR and IoT, information matches real objects with displays on screens, such as VR goggles, and heritage becomes more than mere digital objects; they transform into cyber objects. Although the author did not detail how smart heritage might promote sustainability, this study broke traditional boundaries between smart heritage and smart cities, tending to integrate architectural heritage databases and smart city construction.

Gandhi et al. (2021) studied the missing links between heritage site protection and smart city development planning by identifying museums and heritage sites in Pune, India, as cultural markers and using GIS to examine metro development plans to see if the present geography of museums and historical sites needed to be aligned with Pune's smart city objectives. This study demonstrated that urban upgrades and modernisation cause conflicts in preserving crucial historical and cultural sites. Heritage needs to update in real-time to cope with urban changes.

When cultural heritage evolves, Snis et al. (2021) pointed out, that some complicated issues, such as innovative procedures and heritage digitalisation, should be contemplated during the transformation from traditional to smart initiatives. Smart city solutions offer new ways to manage and promote immovable physical facilities, such as, historic buildings and monuments. This study highlights the role of stakeholder collaboration in cultural heritage management when making an old town smart. The authors stated that it was feasible to address and include a variety of stakeholders' interests by using a participative, interactive digital platform that manages and transmits cultural heritage content. Minh et al. (2021) used smart cultural heritage while developing heritage site management in France. By using smart technology, they found that smart heritage could help maintain heritage sites' tangible and intangible characteristics. It points out that to make heritage smart, an urban cultural heritage framework is required. The framework should consist of cultural indicators regarded as vital components of community infrastructure. To achieve the goal of smart governance, smart heritage indicators must be standardised, consistent, aggregated,

and updated throughout time and space, highlighting cultural and architectural elements. This study team devised a smart cultural heritage management strategy made up of five steps to becoming a smart community: one, data supply management and smart survey programme; two, smart classification criteria; three, heritage management regulations; four, community management; and five, enhanced heritage understanding. Therefore, these efforts towards cultural heritage must fulfil the following criteria: one, long-term development of activities to give heritage preservation information; two, smart and receptive administration of heritage and the community; and three, restructuring citizen-authority interactions with transparency and clarity (Minh et al., 2021).

4. Discussions

4.1 Contribution classification of reviewed articles

Based on articles searched and reviewed in this study, the critical contributions from each article are categorised into five parts. Digital heritage was increasingly discussed by researchers (e.g., Moustakas and Tzovaras, 2010) when a hot discussion wave rolled up in smart heritage. The worth-noting contributions using different technologies are presented in Table 1. The authors of this article believe that heritage digitisation is a foundation for developing smart heritage.

Table 1. Contributions to Digital Heritage.

Authors	Year	Contributions	Adopted technologies
Moustakas & Tzovaras	2010	VR framework for heritage modelling and interactive simulation.	
Husain et al.	2013	Integrated multidisciplinary information not only documents the past and current status of heritage sites but also supports decision-making in the future.	Geographic technology
Thwaites	2013	Software that combines pictures and sound collected at heritage sites.	Tools such as animation and films
Kenderdine	2013	Captured images are combined with narrative techniques to create immersive panoramas of Dunhuang Mogao cave site with rich details.	
Chung et al.	2015	Digitisation affects people's desire to visit historical places.	
Abdelmonem et al.	2017	Virtual heritage has become a popular concept in culture and history preservation, conservation, and interpretation.	3D visualisation and VR
Wang et al.	2018	The proposed strategy brings the interaction into museum digitisation and visualisation.	Device-to-device communication method based on 5G mobile networks, IoT, and WSN
Suwardhi et al.	2022	3D map for documentation of the cultural heritage location would further support heritage protection.	3D GIS, HBIM

Following digital heritage, some researchers are devoted to bringing smart ideas into different fields of cultural heritage. These are summarised as paths and methods of making heritage smart in different layers and scales, as shown in Table 2. Tools adopted in the selected articles are presented in Figure 2. This chart shows that more tools (e.g., AR, 3D modelling, and network) are involved in heritage conservation and documentation as smart heritage discussions increase. Some core theories (Table 3) contributed by scholars are regarded as significant guidance in the smart heritage discourse. A solid theoretical foundation is indispensable to support the discussion and construction of smart heritage. Smart heritage ideas present more interactive and collaborative technologies in academic and application fields of heritage for various purposes, including protection, management, education, and inheritance.

Table 2. Key Contributions in Smart Heritage Developing Paths and Methods.

Authors	Year	Key contributions	Adopted technologies/tools
Chianese & Piccialli	2014	The employment of modern technology sought to turn cultural things into smart objects that can now communicate with one another, visitors, and the network.	IoT paradigm consisting of sensor nodes
Garau	2014	AR on mobile devices dynamically offers smart and interactive solutions in the cultural heritage conservation scenario.	AR and mobile devices
Chianese et al.	2015	Address the complex link between transmitting historical knowledge and visitors' experiences in heritage environments through smart design.	IoT and smart objects
Pocobelli et al.	2018	Make architectural components smart.	BIM
Ardito et al.	2018	Develop interactive methods in which end-users without programming abilities can have smart experiences through the management of interoperable smart objects.	Smart objects or web services are required for the smart experience
Mar et al.	2018	Combine digital sensors with historic sites to collect data and make it accessible to managers and tourists.	Photogrammetry, 3D documentation,
Anwar	2019	People-place linkages might be used to determine a cultural heritage area's smart implication.	Photogrammetry, reality-based 3D documentation, and permanent digitisation
Mitro et al.	2022	The use of advanced technology to bring smartness into heritage.	

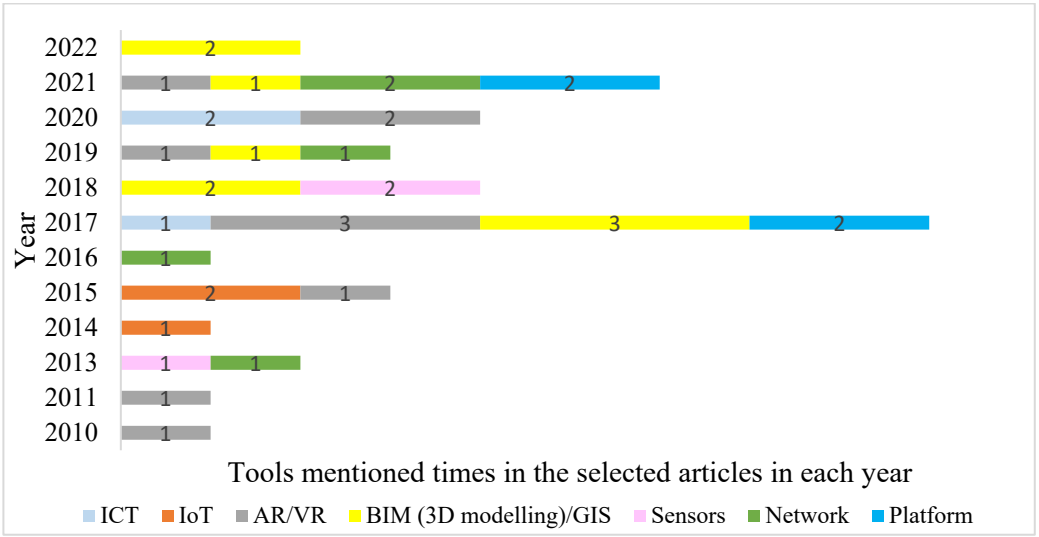

Figure 2. Key Methods or Tools for Developing Smart Heritage Mentioned Times in the Selected Articles in Each Year.

Table 3. Core Theories Contributed by Scholars.

Authors	Year	Mentioned key theories
Bearman	2011	Smart objects in the museum help visitors have a more enjoyable visit.
Chianese & Piccialli	2016	The simple involvement of technologies is insufficient to define a place as smart.
Riganti	2017	Smart solutions should be included in these categories: one, a user-friendly platform; two, an open heritage-mapping platform; and three, platform with a basic set of features, such as high-definition 3D visualisation and real-time data.
rda & Bowen	2017	The smartness needs of cities and cultural heritages require the achievement of contextualised services, which can be made feasible by a shared set of fundamental technologies.
Piccialli & Chianese	2018	Smart cultural environment as a new idea that blends objects, sensors, services, and apps into cultural sites, such as museums, monuments, and exhibitions.
Vassilakis et al.	2018	Smart technologies play significant roles in heritage presentation and communication.
Allam & Newman	2018	Smart cities often reflect the ICT industry, ignoring the cultural and historical characteristics that certain cities have inherited.
Adrian & Kurniawan	2020	Smart heritage development is to help decision-making in cultural heritage protection and create new prospects for economic growth while satisfying public needs of knowing, researching, and preserving.
ṣan & Ciurea	2020	Collaborations with IoT and mobile technologies are indispensable when looking to facilitate smart cultural heritage development, and digitalisation efforts efficiently disseminate key historical data sources and help preserve the past.
Selim et al.	2021	AR brings opportunities for heritage digitisation and visualization.
Stanojev & Gustafsson	2021	Cultural factors influence the progression toward more sustainable options and acceptance and implementation of circular economy ideas.
Gandhi et al.	2021	Urban upgrades and modernisation are causing conflicts in preserving crucial historical and cultural sites.

The more advanced technologies are applied in heritage and urban protection and regeneration, the closer the connection between smart heritage and smart cities. A great deal of previous work corroborates this finding. For example, various ICT tools and knowledge across different heritage areas can extend smart city ideas into a smart heritage concept (Mar et al., 2018). Table 4 lists the crucial theories that involve smart heritage and smart cities based on this review.

Table 4. Key Theories Involve Smart Heritage and Smart Cities.

Authors	Year	Key theories between smart heritage and smart cities
Amato et al.	2013	Cultural heritage is an invaluable global resource, and its relevance with a smart city grows as it is integrated into the digital ecosystem.
Angelidou et al.	2017	Cultural heritage management can be implemented through many smart city strategic areas.
Sindhu & Reshmi	2020	Cultural infrastructure, including notable heritage structures, is an essential feature of cities, which should be included in smart city programmes.
Brusaporci	2020	The smart city approach is directly adopted to process various inputs, stakeholders, and outputs in urban heritage aspects.
Snis et al.	2021	Smart city solutions offer new ways to manage and promote immovable physical facilities, such as historic buildings and monuments.

Smart cities are inextricably linked when defining smart heritage, regardless of the perspective. In each heritage domain, smart heritage has its respective features and definitions: for example, in an exhibition, a virtual cultural exhibiting space is developed with sensors, networks, and applications to provide different services. In the historic building domain, smart heritage regulates and accesses data connected to historic buildings and their surrounding regions, preventing existing danger factors. Based on this review, the interpretations of smart heritage from reviewed articles are summarised in Table 5. Following this, a timeline of milestones in defining and developing smart heritage is presented in Figure 3.

Smart heritage is still a novel concept. The popularity of this topic began about ten years ago, covering fields ranging from archaeology, tourism, and architecture to information, technology, and the Internet. Research from 2013 to the present significantly defined smart heritage and formulated its indicators. Following this review, the authors of this article believe that smart heritage should be developed in smart cities, and they can be regarded as two interacting concepts. Developing indicators to define smart heritage seems a necessary step as a broad concept.

Table 5. Interpretations of Smart Heritage from Reviewed Articles.

Authors	Year	Smart heritage interpretations
Qiu et al.	2015	Smart heritage in the archaeological domain can be understood as a comprehensive system capable of operating and managing heritage data and providing heritage presentation.
Della Corte et al.	2016	A virtual environment established by employing ICT to satisfy requirements of different stakeholders, such as online heritage touring, heritage protection, and sustainable cultural promotion.
Khoshelham	2018	Smart heritage can be described as achieving more rational decision-making in heritage building conservation with the involvement of spatial data and BIM.
Neve	2018	Placing the idea of heritage at the cities' core, smart heritage should be understood as a coevolving assemblage of built environment and people, and heritage smartness research is claimed to be critical for sustainable urban development.
Balducci et al.	2020	Heritage smartness should become a system aggregating advanced technological tools and satisfying the stakeholders.
Lerario & Varasano	2020	Smart architectural heritage should not only bring systematic opportunities with monitoring and protecting function into heritage but also link heritage with urban data processing, environmental monitoring, economic growth, and public services.
Angelidou & Stylianidis	2020	Smart heritage to achieve the following various goals: one, improving visitors experiences; two, raising public awareness of a specific cultural heritage; three, preserving cultural heritage, and four, better managing conditions and utilities in heritage sites.
Minh et al.	2021	Smart cultural heritage management strategies are listed as follows: data supply management and smart survey programme; two, smart classification criteria; three, heritage management regulations; four, community management; five, enhanced heritage understanding.

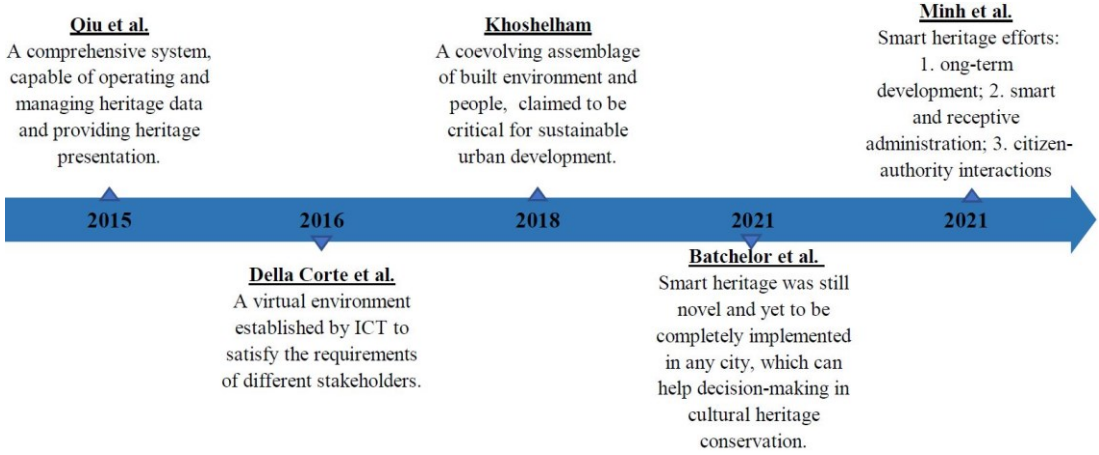

Figure 3. Timeline of Milestones in Defining and Developing Smart Heritage.

4.2 Smart heritage indicators and novel understanding

According to the above-mentioned tables and figures, based on standard systems developed by Riganti (2017), Adrian and Kurniawan (2020), and Minh et al. (2021), smart heritage from theory to tailored application and service objectives, should be incorporated into the following indicators (Table 6).

Table 6. Indicators and Effect Factors.

Indicators	Effect factors
Heritage digitisation	Cost Technology
user-friendly platform	Data collection Data integration Data analysis
Service objectives	Requirements Benefits
Application optimisation	Users feedback New reuse

Finally, based on this review, the framework for developing smart heritage should comprise the following stages:

- heritage digitisation and visualisation using technologies, such as photogrammetry and 3D scanning, to form digital base plates
- with presentation through BIM, GIS, or both, or other types of models, a user-friendly platform construction through adopting techniques, such as WSN and IoT, to generate real-time interactive data
- identification of service objectives to develop different applications with the help of heritage models and data—for example, developing an app to enable virtual touring on users' smartphones and establishing a safety monitoring system for heritage buildings
- collection of user feedback to enhance and optimise applications

The authors of this article provide a new understanding of smart architectural heritage as architectural heritage is visualised through 3D modelling technologies and connected with numerous urban components through techniques like IoT to reach different goals in sustainability. These goals include heritage modelling for protection, developing virtual museums for touring, educating the following generations in history, and structural health monitoring of historic buildings.

5. Conclusions

This article conducts a holistic review of smart heritage to address its definitions within sustainable development and present its definition in the architectural field. Meanwhile, a few review articles cover smart heritage in academia, which provides a reference for scholars from different disciplines to interpret and develop heritage smartness. Smart heritage as a concept broadly covers various aspects of heritage and technology. Digitisation and visualisation support informative and interpretive applications in different contexts. Different applications follow in the footsteps of earlier discussions and extend to detailed research by adopting more advanced technology. As a broad concept, smart heritage definitions should be refined into different sub-research areas, as each represents a different application and contribution, even though they are interoperable. This article presents indicators for smart heritage definition and a framework for its development, including criteria and technology adoption for different purposes. They are novel outcomes which pave the way for more relevant studies. As another novelty, smart architectural heritage from a new perspective is interpreted as using technologies, such as 3D modelling and IoT, to manage architectural heritage to satisfy various requirements, including documentation, virtual tour, and adaptive reuse. Smart city solutions apply to heritage smartness, and smart heritage development contributes to the progress of smart cities. Therefore, the concept of a smart city should also come into play regarding smart heritage. The authors believe that the ways to make historic buildings smart within the smart city context will come to the fore in future research, bridging smart cities and heritage fields. This review has some limitations: 1) the search is limited to articles in English, and 2) phrases used in different studies may not be covered by the keywords used for the search. Further research is needed to consider more influence. Nevertheless, the authors of this article contend that a continued evolution exists in standard system establishment and further expansion in smart heritage understanding. Detailed subdivisions might include integration between different disciplines, approaches considering citizens and communities, deepening sustainable future urban development, and optimising smart heritage outcomes and their practical applications.

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Conflicts of interest

The Author(s) declare(s) that there is no conflict of interest.

Data availability statement
The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

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Studies involving human subjects: No human studies are presented in this manuscript.
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