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The IoT as a Key in the Sensitive Balance between Development Needs and Sustainable Conservation of Cultural Resources in Italian Heritage Cities

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Abstract: In recent years the application of information and communication technologies (ICTs) to the built heritage has been increasingly finalized to heritage promotion in order to maximize visitor flows. New urgent challenges facing built heritage loom now over its very existence and our possibilities to preserve it for future generations. Italian heritage cities represent a delicate context, where concerns related to tourist flows and resource consumption are amplified due to the concentration of sites and points of interests in urban areas, also in very small ones, while tourism remains vital for economic growth. In such contexts, balancing economic development and sustainable heritage conservation demands well-calibrated tools and approaches. The article presents an overview of the ways the Internet of Things (IoT) is currently used to solve urban issues and support heritage projects. On this basis, and considering the characters and problems typical of heritage cities, as well as the features of the Italian scenario, the most appropriate application lines of IoT for the Italian heritage cities are identified. Then, their potentialities, the mutual impacts between them and the heritage field and the key role of the IoT in supporting the delicate balance between economic development and cultural resource conservation are finally discussed.

Keywords: Internet of Things; heritage cities; ICTs for cultural heritage; built heritage; sustainable heritage fruition

1. Introduction

The Italian cultural heritage, especially in its built expression, represents one of the most important features of the national landscape and, at the same time, one of its main resources for socio-economic as well as cultural development. Globalization contributed to widening the public—and the publics—for the presentation of those resources, amplifying the knowledge of the most famous ones and extending it to those still unknown. This has made tourism the driving force of local and national economy, but also, in its most 'massive' expressions, a highly impacting element, particularly in urban contexts.

The increased demand for cultural offers, on one hand, and the general problems of cities, on the other, have been highlighting that an excessive and inappropriate use of the built heritage can be harmful for its physical existence and for its harmonious relationship with the environment. As a matter of fact, on one hand, the intensive fruition of the built heritage exerts direct impacts on the physical component of cultural resources. On the other hand, some of those effects spread also over their context. The complexity of such phenomena is evident, above all, in the multidimensional character of impacts, affecting cultural tourism destinations under the environmental, economic and social respects of sustainability. Such complexity emerges dramatically at the urban scale. Then, since the built heritage is a fundamental component of Italian cities, the pursuit of urban sustainability cannot overlook how built heritage use affects the overall sustainability levels, increasing the difficulties in achieving it.

The Italian Strategy Tourism Plan for 2017–2022 [1] identifies specific leverages for the re-launch, on new channels, of Italian leadership in the international tourism sector. Those leverages are technological innovation, coping skills towards market transformations, competences upgrading, growth of business activities and cultural heritage promotion. With reference to the latter, however, the relation between tourism and heritage is still interpreted from a purely economic perspective. In fact, heritage is expressly acknowledged in the role of tourism activator. In turn, tourism is recognized as being able to increase heritage financial sustainability and strengthen its enduring management prospects. In the document, the awareness of tourism effects—and the call for more sustainable tourism models—are referred exclusively to naturalistic areas with environmental or landscape value. A similar awareness of effects on the built heritage is, indeed, lacking. In particular, a reading of cultural urban destination as "pieces of heritage" can be perceived, which does not grasp, at the same time, also their ultimate nature as 'cities'.

Furthermore, in recent years, the massive use of ICTs in the field of cultural heritage has been exerting contrasting effects. On one hand, it has shed light on resources still unknown to the global scene, but it has also exposed to new intensive visit flows sensitive local heritages. These are generally unprepared to sustain or manage them by defining appropriate fruition and use models.

On the other hand, the United Nations Educational, Scientific and Cultural Organization (UNESCO) [2] has also put into light, among the risk factors for loss and deterioration of the built heritage, specific elements related to the use and knowledge of tangible cultural resources.

It has become clear, then, that physical conservation today cannot be tackled any longer on the basis of a conventional risk map. Actually, threats to heritage come not only from the gradual development of natural and anthropic factors such as physiological decay or from extreme events, but also from incorrect interactions with it, for knowledge and visit purposes.

Consequently, the issue arises of finding a delicate balance between the two ultimate goals of economic development of territories and built heritage preservation.

In such a scenario, technological advancements have had a role in catalysing cultural consumption processes over the last decades. Then, the need to assess technologies' abilities to reverse the course of development processes and to act as adjusting agents emerges clearly.

ICTs have been effectively supporting cultural resource promotion projects for knowledge and promotion purposes. But, if heritage risk causes are also related to the visitors' and managers' knowledge and use, and not only to what we traditionally identify as risk factors, it becomes evident that ICTs also need a rethinking. In particular, it is necessary to redirect them no more towards simple heritage promotion or to mere physical preservation, but from a multi-purpose perspective.

The Internet of Things has achieved a particularly high penetration level in people's everyday lives, due to the availability of a variety of devices, with a wide range of performance and cost levels. As an example, it is estimated that by 2025, the overall number of circulating IoT devices is expected to reach 75 billion [3], and their ability to pursue sustainability in cities is being more and more acknowledged. Nevertheless, in heritage cities this issue is not dealt with extensively; actually, studies deepening the application of IoT to urban cultural heritage are hard to find.

The IoT has proved its capacity to connect assets, objects, devices and people, and its ability to create "intelligent" environments. The question arises, then, whether it could contribute in facilitating the match between the two goals and realizing the subtle and complex balance between the physical preservation of tangible and, particularly, built cultural heritage, and economic development. The present article aimed to assess this possibility. To this end, this central theme was deepened and contextualized to the urban dimension of the built heritage. Heritage cities, where such balance is jeopardized the most, were chosen as investigation field, with specific reference to the Italian context. In the following paragraphs a background analysis of IoT application is presented with reference to both urban contexts and cultural heritage, useful to outline its possible contribution to heritage cities. Then, possible directions for IoT solutions appropriate for Italian heritage cities are outlined. Finally, mutual impacts between IoT solutions and built heritage are identified and discussed under different respects. In order to categorize the multifaceted implications of these mutual relationship, the PACT model from the user experience domain will be useful to identify main concern areas that can be affected by them: People, Activities, Contexts and Technologies [4].

2. Background

The Internet of Things has undergone an articulated evolution process from its first formulation by Ashton [5] throughout several stages. In the initial phase of 'pre-IoT', plain sensor networks able to detect information and transform it into digital data were queried almost "manually" without the support of the internet. Since then, the passage to current complex solutions was not immediate, in the sense that it was not accomplished by simply connecting them to the web. By subsequent steps, more and more sensors' functionalities have been added in time [6]:

- the ability of connected devices to transfer specific data;
- the ability to detect and transfer more data types;
- the possibility to enact a sort of selection through basic preliminary elaboration;
- the performing of tasks based on instructions;
- and finally, the ability to perform actions based on a local elaboration capability.

In this sequence of consecutive refining levels, other devices (actuators) have been gradually integrating sensors, bringing about higher and higher levels of intelligence in the overall systems.

Many definitions of the IoT can be found by now, and its presence is spread in our everyday lives in many sectors, with varying maturity levels. The following paragraphs outline the main features of the IoT diffusion in the two most relevant domains for the aim of the work—cities and heritage, and describe the context of the study.

2.1. Use of IoT for Urban Issues

The spreading of the IoT concept embraces by now many aspects of everyday lives, even very complex ones, proving its ability to deliver large-scale solutions for whole communities. The urban level appears as the most appropriate dimension in which it can simplify actions and support decisions to solve a range of problems that typically concentrate in cities. In the latter, actually, population growth and the increasing differentiation of activities amplify complexities in task management. In this sense, the IoT has soon turned out as a substantial support for local administrations and planners of urban development and services. Globally, implemented solutions range in all facets of public and private life, up to being applied in the "smart cities" concept. Applications, however, mostly concentrate in specific domains: mainly transport optimization, pollution control and resource management.

2.1.1. Urban Transport and Mobility

This is the sector with the widest profusion of experimentations, for many reasons. On one hand, the growing demand of transport is to be considered, together with the inadequacy, in many cases, of road networks to support it. On the other hand, new mobility models (carpooling, car sharing, charging point networks), which have recently appeared on the global scene, are considerably innovating the use patterns of available infrastructures. Finally, the possibility to create direct utility for end users, and not only for urban managers, through real-time data for recurring problem solving, also has a role in it. The opportunity for people to perceive tangible returns of implementations also through the wide availability of wearable devices such as smartphones is another probable reason for diffusion. The tasks addressed by applications are disparate, from the localization of unoccupied parking areas [7] to analyses on bike sharing [8] or cargo-bikes [9] implications, to the general management of traffic issues [10–12], to optimal route planning and accident prevention [13] and in general to the increase of road safety [14]. In this respect, the predictability of events intersects the planning of improving actions on road infrastructures [13]. The most investigated sector is, anyway, supply chain management;

an interesting cause for reflection and further deepening is the stress on the importance of users' urban knowledge [15].

Unavoidably, the most explored technical segment is mobile sensing; in any case, solutions adopted generally refer to the communication among vehicles or between vehicles and road networks, requiring the use of different types of sensors, on mobile or fixed devices, such as smartphones, cars, bike parking areas, traffic lights, crossroads, collection/delivery and refuelling/recharging stations. Such heterogeneity, on the other hand, emerges as a criticality in the devices used, together with costs and difficulties in management and maintenance [11].

2.1.2. Pollution

Implemented solutions are aimed at the acquisition of real-time pollution levels, in order to identify their contamination degree [16] or predict the composition of fine particulate matter [17], with technological equipment based on machine learning [16] and on the use of multi-type sensors. Among them, mobile crowdsensing is getting a foothold, due to the spreading of smartphones; this, although it fosters community engagement, entails the need to solve problems as to the reduction of errors due to non-expert users, high consumption of end devices and difficult data management [18]. Acoustic pollution is also being investigated [19,20]. With reference to computing, cloud-based solutions share the scene with different configurations, based on edge- and fog-computing [16], yet the preferability of a segment in respect to others has not emerged yet.

2.1.3. Efficient Resource Management

The main concerns addressed relate to energy, water and waste.

Energy—many applications focus on efficient energy management and electricity consumption reduction, at different scales. Solutions range from the field of public services such as public lighting [21–23], to private Smart Building (through the integration of different building systems and related maintenance processes for the optimized management of whole building stocks [24–27]). The individual dimension is also supported in the Smart Home sector, with the interconnection and remote control of electric appliances through smart metering, enabling the active role of non-expert residents [28–32]. Other applications are related to Micro Smart Grids for the connection of urban areas such as hospitals, school complexes, shopping centres [33].

Water—the limited availability of water for different uses and needs of the population is becoming a major problem, not only in developing contexts. As a consequence, specific attention is paid to the water supply system and to the practical possibility of water wastage reduction. In the implemented systems the strategies are variegated, from real-time control of flow leakage in networks [34], to the monitoring of tank levels through electronic water level sensors, in order to prevent overflooding [35]. Solutions specifically focus on the search for a compromise between centralized management systems and decentralized sensor networks, also supported by robots [36]. Other solutions address water quality issues [37] by implementing systems for contaminant control and treatment management [38–40].

Waste—the management of waste has also become a big urban concern. As a consequence, the push for the definition of appropriate solutions is strong, for both the management of their physical presence in the urban landscapes and their processing as a secondary resource. Many systems try to deliver reliable solutions to the specific issue of garbage collection, often through the use of smart bins. Some examples are the integration of the predictability of the filling level with the optimization of waste collection through optimal route definition [41], the management of physical separation, e.g., with moisture sensors for the separation of wet and dry garbage also on site [42], associated to incentive schemes [43] and the fundamental use of mobile apps, with ultrasonic, often low-cost sensors [44]. More comprehensive approaches are also present, addressing the whole management process in its different collection, separation, transport, placement in temporary stocking areas and treatment centres [45,46].

2.1.4. Urban Gardening

A smaller number of applications relate to new interesting urban practices, consisting in the effort to reconciliate the management of natural environment with the urban dimension, both on a genuine individual pattern [47] and in economic or production-related terms [48,49]. It is the so-called 'urban gardening', with applications aimed to the optimization of water and fertilizing use to support the growth of plants through remote control. The basic principles are very similar to those implemented in the agrifood sector, with respect to which also practical solutions are comparable, blurring the borders between the two fields. Supported tasks mainly relate to the control of micro-environmental conditions (temperature, relative humidity, soil moisture, conductivity, lighting, CO_2, water resource levels), resource use planning and uncertainty management, while implemented technologies are mainly based on the integration of cloud computing and 'mobile' applications [47–49].

2.1.5. Smart Cities

More generally, many efforts are directed towards the concept and the possible declinations of the "Smart City", of which the IoT is considered the "fundamental enabler" [50].

The "Smart City" paradigm is described in the EU definition [51] as a six-dimensional concept:

- Smart People—citizens' engagement and participation; bottom-up decisional processes; participatory policies,
- Smart Governance—centrality of the human capital, environmental resources and communities' relationships,
- Smart Economy—productivity and occupation growth through technological innovation,
- Smart Living—citizens' comfort, well-being, health, education, safety, culture,
- Smart Mobility—cost reduction, environmental impact reduction, energy saving through intelligent mobility management,
- Smart Environment—sustainable development, low environmental impact, energy efficiency.

Beyond conceptualizations, in many cases the proposed solutions consist of different efforts to combine various strategies for the solution of single problems, with the goal of activating urban intelligence in the residents' life as a result. As observed in Zhang et al. [52], a strong proposal for the realization of whole IoT frameworks supporting the city as a whole system is still missing. On the other hand, the main problems of smart cities have clearly emerged. These substantially consist in the huge amount of data to be managed, their heterogeneous nature in terms of source, resolution and format and their difficult interoperability [53–55]. Another big problem lies in the difficulty for end users to understand them and, then, to be able not only to use them but, even before, to be motivated to do it, if they cannot grasp their practical return. Beyond this, the availability of tools and devices such as smartphones [52] suggests the need to include semantic relations in implementations, in order to decrease the whole system's complexity.

On a technical level, efforts to achieve a compromise between complexity and manageability of smart infrastructures can also be found [56]. The combination of cloud computing with strategies to reduce the training times on large Graphics Processing Units (GPUs) by strengthening the potential of network edges is also an interesting point [57].

More generally, however, such complexity in meaning, unavoidable despite technological solutions, is to be considered, especially with reference to the passage from the IoT to the IoE (Internet of Everything [58]), including users among interconnected nodes. In fact, their exclusion from action possibilities, due to the limited understanding or motivation, can significantly hinder such further evolution.

Examples of implementations taking cultural heritage into consideration are not very frequent, testifying a difficult reconciliation of cultural heritage values with smart cities principles [59].

2.2. Use of IoT for Built Heritage-Related Issues

The field of cultural heritage has been experiencing, in recent years, a deep renovation, especially in the domain of promotion for divulgation and tourism purpose, thanks to ICTs. Through the development of new models for cultural resource communication, ICTs have allowed visitors to know and explore the variety and richness of a partly unsuspected heritage: museum collections, archaeological sites, monuments and historic buildings. Multimedia technologies for the definition of visit itineraries (interactive terminals, multimedia halls, audio guides, video guides) on one hand, and the development of augmented reality and virtual reality, on the other hand, have had a great role in it. Indeed, new cultural offers are marked by an extreme integration of heterogeneous information and expression means and by personalized, simplified and interactive fruition modes. As a matter of fact, applications range from multi-sensorial information materials simulating real visits to immersive serious games or edutainment [60]. The internet has also allowed to extend in time the possibility of heritage knowledge, releasing it from the physical visit, making virtual visits available to users unable to enjoy on-site visits. Nevertheless, contrasting approaches coexist today, since together with simple and effective solutions, many others have appeared, built around show-off purposes, an end in themselves. Regardless, in more recent years, the pursuit of the 'wow' effect, i.e., a perception of utmost excitement, fascination, admiration, enchantment and surprise [61], in the presence of impressive objects, products or situations, has been gradually put aside in favour of unique and engaging experiences for visitors. The advent of the IoT, with its infinite ability to connect entities, can offer huge potentialities to heritage.

In this domain, however, those opportunities have been explored, until now, with a very sectorial approach. In fact, research lines mainly refer to two specific and separate purposes: cultural resource promotion and heritage physical conservation, each with dedicated efforts and applications.

Currently, the valorization and fruition of the built heritage are pursued by IoT applications mainly through the focus of user experience (UX), a multidisciplinary research area investigating end-users' perceptions as they interact with a product, service, or system [62,63], reinterpreted extensively to encompass on-site visit, pre- and post-visit phases, along the double line of personalization and interactivity.

As for the latter, most applications support both the demand and the offer of cultural resource consumption, availing of innovative narrative means to enable content creation and heritage storytelling [64,65], from the part of both managers and from users (content and value co-creation). An example is a specific authoring toolkit for the composition of physical/digital storytelling by heritage professionals, within platforms for the design of smart tangible exhibits [66]. Across implemented solutions, mobile crowdsensing (MCS) and mobile cloud computing (MCC) are being established as the main IoT technologies in the promotion of smart connected communities, integrated with big data analytics for sustainable cultural heritage. MCS refers to a broad range of community sensing paradigms [67], while MCC is a combination of cloud computing, mobile computing and wireless network, aiming to bring rich computational resources to mobile users, network operators and cloud computing providers. The infrastructure makes it possible for rich mobile applications to be run on a large number of mobile devices [68]. To this end, both data storage and data processing occur outside of the mobile device, in powerful and centralized computing platforms located in clouds. Thus, mobile devices do not need powerful configurations such as processing unit, speed and memory capacity, because all the complicated computing modules can be processed in the clouds [69].

As for personalization, solutions focus on the possibility to offer deeply customized visit experiences to the general public. From this perspective, the search for impressive impact seems to have been gradually replaced by more genuine approaches, careful towards the expectations, needs and exigencies of a demanding and increasingly differentiated public. The personalization of visit experiences is investigated mainly for museums, collections and archaeological sites. Interesting studies can, however, be found also about the relationship between humans and built spaces within monumental buildings, based on the tracking and analysis of different users' movement alternatives, with or without preventive knowledge of the building [70].

In particular, a recurring approach is the combination of sensor networks with data analytics for the collection and analysis of behavioural data. Such approach supports the definition of cultural offers that fit visitors' preferences with mutual benefits for managers and users in terms of, respectively, increased revenues and higher satisfaction [71–73].

In those experiences, a special role is played by sensors such as Beacons, for indoor localization, recommending and tracking of users, and the cloud as enabling technology, as strategic support for museums of small dimensions and with a limited financial budget [74]. Here, it becomes possible to transform the displayed resources in "talking" objects able to tell their story to the approaching visitor [75]. In some cases, the focus is on the playful engagement, e.g., in the interactive and immersive gamification, with wearable devices and smartphones, or otherwise aimed at the user's entertainment [76,77]. In general, the common pursed principle can be defined as 'context-aware content delivery', through the definition of personalized visit paths [78,79], sometimes considering also specific physical or cognitive disabilities [58,80,81]. The tracking of visitors and their spatio-temporal visit patterns, in order to deduce their preferences and impressions, is mainly directed towards increasing the possibility of replicated visits in time, in a sort of fidelization strategy.

As for IoT contaminations, the integration with Building information Modeling (BIM), a 3D digital process method for modeling, generating, managing and controlling information about a building project during its entire life [82], is still under debate. For a part of the research community such integration represents a process of coordination of all phases under an adequate knowledge-based approach [83,84]. For others, the two fields are technological domains of deeply heterogeneous nature, hard to reconciliate [85].

Efforts to overcome the acknowledged limitations of the IoT paradigm on the practical level—mainly the difficult integration of different technologies in the creation of IoT general architectures—can also be found.

All these experiences stress interactivity between users and cultural resources. However, the direct contact with buildings, both as cultural resources in themselves as historical, architectural and religious buildings, and as 'containers', as is the case with museums, is missing. Additionally, in the latter case, the pluralization and personalization of paths in museums is aimed to support the visitor-resource connection, disregarding the relation between users and the built space in all its implications.

In other cases, the semantic relation among physical objects, place and digital resources available is investigated [86] among geospatial digital information contained in repositories. The semantic issues affecting heritage remain, however, confined to contents without involving users and their relation with cultural resources, particularly the built ones.

Apart from the full semantic involvement of users, which has not really been achieved yet, the central role of users is anyway readable in practical experiences, approaching the passage from the IoT to the IoE. The latter also considers persons as interconnected nodes, together with objects, devices and building parts [58]. Nevertheless, such extension of the relation among users, resources and technologies is not fully explored in terms of its potential.

A rather new discipline is finally emerging. The Internet of Cultural Things (IoCT) is a specific pervasive and ubiquitous application of the IoT paradigm to cultural heritage aiming to support interactive models of fruition, heritage safeguarding and promotion and make heritage-related process management more efficient, sustainable and cost-effective [87,88]. Elaborations are however very limited, as is also the case with the new emerging concept of "Cultural Computing" (CC), a novel field of human-computer interaction, which covers the cultural impact of computing and the technological influences and requirements for the support of cultural innovation, including also cultural heritage among its concern areas [76]. Cultural Computing goes beyond the simple integration of cultural aspects into the interaction with computers. Actually, it aims to allow users to experience an interaction closely related to the core aspects of their culture, availing of multimedia communication carrying non-verbal, emotional and unconscious information [89]. A major advantage of CC is acknowledged, among other things, in terms of enabling users and researchers to access from a distance resources previously inaccessible or at a risk of loss [76].

In general, in many realizations, the term 'sustainable' is identified with the concept of 'smart' and 'interactive' [90]. This is probably true with reference to solution inclusiveness (social sustainability), but leaves other questions open, such as environmental and economic issues, without further supporting the statement with specific arguments.

The other major goal of the technological projects developed—the physical conservation of cultural resources—relies at the moment on sensor networks, both basic and advanced, as a main strategy for structural and microclimatic monitoring and diagnostics of sites and buildings. Solutions are often based on different technologies' integration and varying solutions for storage and computing (public or on-premise cloud) [91–93]. Solutions refer also to structures integrated with heterogeneous sensors allowing the simultaneous monitoring of different parts of buildings [94] or supported through virtual reality and drones for inspection tasks [58].

On the conceptual level, despite technology advancements, heritage does not substantially acquire a 'systemic' dimension in itself. Indeed, there is no meaningful sign of deep connection among resources or systems of resources. Only a sort of 're-seaming' is obtained with the use of technologies similar to those spread in the whole urban system, such as for example IoT lighting systems [95]. Otherwise, heritage is not considered in its entirety, e.g., as a relevant component in the urban-scale conceptual declinations of "Smart Cities" (2.15) or urban "Digital Twins". The latter are virtual replicas of a city or digital representation of urban networks using real data obtained from the monitoring devices within the city [96] that can be examined, altered and tested without interacting with it in the real world [97]. The only possibility for heritage to be included in the development and investigation of the systemic nature of cities relies, then, only on IoT technologies, whose current 'case-by-case' approach limits, on the other hand, its full potentialities.

2.3. Heritage Cities as High-Complexity Contexts

As described above, the Internet of Things has been long demonstrating its potential in urban issues and cultural heritage, with an abundance of high-level and reliable practical solutions, but also with a strong limitation, represented by the sectorial character of applications.

A demonstration of the difficulty to reconciliate those two major concern areas comes also from the EU definition of the six-dimensional 'Smart Cities' concept, described in Section 2.1.5. None of those dimensions considers expressly cultural heritage, and built heritage in particular, nor communities' relationship to them.

Due to the separation of the two focuses mentioned—the urban scale of applications (Section 2.1) and cultural heritage (Section 2.2)—the dramatic criticalities of heritage cities, a domain requiring context-tailored solutions, remains unsolved. In such scenarios, complexities reach a top level, since the typical problems of urban contexts overlap with cultural heritage issues and tourist destination concerns, requiring careful consideration.

European built heritage has a peculiar consistency, gathering about 300 of the 1121 UNESCO world heritage sites; such inheritance, then, marks European and, particularly, Italian landscapes, peculiarly. What specifically characterizes the built heritage is its urban dimension, since in the complex of cultural resources, a preeminent position is held by heritage cities. Here, whole portions of the urban fabric (historic centres, complexes, neighbourhoods) have significant historic, cultural and architectural values. The configuration of the built heritage is such that, together with the many urban cultural 'places', as many parts of the built fabric dedicated to related services (accommodation facilities, information points or others) are also to be considered. So, from the point of view of fruition—mainly through tourism activities but also through daily use and re-uses on the part of residents—this has unavoidable repercussions on the whole urban system, in terms of processes and resources.

Tourism activities, in particular, bring about an increase of complexity levels in urban contexts. This complexity is reflected in many different respects. On one hand, cities in themselves have a multifunctional nature; on the other hand, in the urban context different built forms, styles, customs and cultures coexist, not always harmonizing with each other. Finally, many 'micro-destinations' can be found in heritage cities, such as monuments, ancient centres, points of interest. In addition, the expression "urban tourism" is, far from being univocal, rather a category, encompassing cultural tourism, sports tourism, business tourism, together with many different forms, that are, each one in itself, "urban tourisms". Actually, "urban tourism" is more than tourism within cities, but, as pointed out in [98], a type of tourism activity in a multifunctional and complex environment urban space characterized by non-agricultural based economy—such as administration, manufacturing, trade and services—and by being nodal points of transport, offering a heterogeneous range of cultural, architectural, technological, social, natural and business experiences.

Furthermore, in the use of the "space" as a resource as well as all other primary resources in cities, it is hard to discern between tourists' and residents' shares and patterns.

This complexity of urban tourism has represented the case for the development of several theorizations. The systemic approach [99] identifies a tourism as an "event" that increases urban entropy (meant as the opposite of sustainability) unbalancing urban functions. Consequently, this entails traffic congestion, overcrowding, gentrification (residents' displacement, urban ousting) break out, together with conflicting uses of spaces and resources.

With reference to possible impacts, a large part of the community research has long been stressing the "double blessing" character of tourism, for its potentiality to deliver financial and social advantages to local communities and contexts together with an unavoidable deterioration of environmental and material assets. Heritage tourism is one of the main expressions of urban tourism, the one with the fastest growth rate in the general sector, and for the reasons explained above, for the most part it occurs and evolves within cities. It perfectly embodies the so-called "tourism paradox" [100], i.e., the trend of tourism activities to dissipate their very nourishment.

More precisely, tourism is a high-impact sector, because it produces a disordered and uncoordinated development of cities with the overexploitation of environmental, social and economic resources as well as of spaces and of the built heritage. This point, referring to the major resource of communities enshrining historical, cultural and artistic values outlived to time's injuries for ages, sometimes encumbered by heavy modifications, often remains overlooked.

Certainly, cultural tourism is nourished by places' identity, image, and original characters and by the uniqueness of its surroundings, and can potentially support heritage in expressing itself as an added value for the residents' communities. Indeed, the development of the tourism chain helps to elevate the revenues and the living conditions of the inhabitants and of all the stakeholders involved in the related sectors. It also represents a strong motivation for people's pride towards their identity and their past generations' inheritance. One of the ultimate objectives of cultural tourism is favouring the preservation and enhancement of the complex of local values—in historical, environmental, cultural and aesthetic terms—reconnecting resources among them and to the economic and physical development of cities. A further paradox is, then, the fact that tourism tends to reassess and preserve heritage's cultural value, but also to deteriorate its materiality. Nevertheless, heritage protection, on one hand, and economic interests on the other mainly act as contrasting forces within a match whose fortune depends on circumstances. Consequently, it is very difficult, and a delicate task, to harmonize cultural priorities and economic profit, or balance sustainable management of cultural heritage and socioeconomic development needs.

In the first place, the effects of intensive and excessive fruition reflect on the conservation state of heritage assets: voluntary or involuntary damage difficult to prevent in crowded contexts, effects on the microclimate of delimited spaces and the alteration of environmental parameters, and so on. These add to the problems that traditionally affect the built heritage regardless of its location (whether in cities or not), such as exposure to the risk of extreme events and the general limitation of dedicated budget for conservation and maintenance.

Moreover, the impacts produced through the intensive fruition of heritage extend far beyond individual resources, affecting the whole urban context.

In the "vicious circle" of destinations' development cycle described by Russo [101], the development process of tourism in heritage cities can become highly unsustainable. In the initial phase, first tourists ('pioneers') are individuals with a specific inclination to cultural and aesthetic contents. As the city gains in reputation as a destination, the rise in arrivals determines the first investments in infrastructures and services. This, in turn, activates and fosters a more intense urban development, with conspicuous tangible and intangible advantages and a strong push to the local economy. In the maturity phase, global instead of local stakeholders come into play, monopolizing the delivery of goods and services, uncaring of residents' interests. Thus, for the whole system of the city, further phases of stagnation and decline begin, in which the increase in costs is not balanced through benefits for the resident community and the local economic system collapses. The tourist area expands outside the central areas due to the growing demand, while cultural resources and related facilities (buildings, roads, parking areas), concentrated in the centre, are overexploited. When the tourist market reaches its saturation point, satellite businesses related to it are swept away due to the increase in central areas' costs. Strict tourist activities keep their location in the city centre, which is thus monopolized by tourist functions, and gentrification begins. At the same time, residents' tolerance towards tourists, very high in the beginning, decreases drastically due to the absence of visible advantages for local communities.

The problems related to the intensive fruition of heritage, such as overtourism, resource consumption, loss of significance, congested mobility, assume then in European heritage cities large and systemic dimensions, not concentrated on single sites or monuments, but rather diffused. This criticality is destined to grow further in time, as it is estimated that by 2030, 68% of the world population will live in cities [102]. It requires then sustainable solutions for the management and conservation of cultural resources, which are also context-sensitive.

3. Proposed IoT Approaches for Heritage Cities in The Italian Context

The Italian context of heritage cities is particularly variegated from the north to the south, comprising main famous destinations such as Roma, Firenze, Napoli, Venezia, Verona, Perugia, Lecce, together with less extended, but equally valuable towns such as Matera, Siracusa, Urbino, Orvieto, Fabriano, Assisi, Noto, and small municipalities or centres, such as San Gimignano, Alberobello, Pienza, Fontanellato, Gradara, Cisternino.

In such a kaleidoscopic heritage, ICTs have been long unfolding their potential for well-defined purposes, mainly separating physical conservation and tourist promotion of resources, which are, as mentioned above, much more interrelated as can be thought. In the wide scenario described above, where the extent of impacts affects the whole urban system, it is crucial to rely on solutions conceived from a wider perspective, which:

- look at heritage within a systemic approach to city and its unicum (resources, barriers, users);
- look at heritage fruition and at users' relation to it no long as conceptually separated from cultural resource conservation, since the former influences significantly the latter and can thus represent a possible action strategy for its pursuit.

As explained, the IoT can operate a deep change in the way we approach heritage and solutions for it in favour of a more systemic perspective, as it requires and deserves. Possible solutions, however, need to be carefully calibrated in respect to the context.

In the general debate, a traditional distinction prevails between large cities and smaller towns, attaching to them great differences in relation to heritage-related objectives. In particular, Reference [89] identifies for 'cities' the liveability of present as main task, against the more time-spanning goals of 'towns', engaged in the simultaneous pursuit of greater liveability, future development planning and recovery of past values. As a consequence, technological solutions are also developed from within well-separated domains and built upon different basic principles. Furthermore, from a "structural" perspective, there is a prevailing belief that small towns are rather underdeveloped and decaying in respect to cities: "Smart towns are facing serious challenges, including declining downtowns and incompatible development in historic areas/loss of community character, loss of natural areas and open space, suburban-style large-lot growth at city edges, limited housing choices, lack of transportation options, limited planning capacity, and opposition to regulations" [103].

In the Italian context, large and medium-to-small urban contexts are not so sharply characterized, at least with reference to the wide field of heritage cities and towns. On one hand, it must be considered that also in large heritage cities there is the strong need to preserve the values of the past, due to the depersonalization resulting from complex urban dynamics. These are linked to intense flows of all tourism 'modes', but also to employment-related displacement and immigrant flows of last decades; moreover, 'cities' are also engaged in reducing the complexities of development through correct planning actions.

On the other hand, exactly for their marked cultural value, small heritage 'towns' are also currently invested by a huge and growing attention to their new and alternative cultural offers and in general to a re-evaluation of their peculiar lifestyles. Due to a stunning growth of visit flows—foreign and domestic tourists 'discovering' those new destinations and their treasures for the first time—small towns, just like big cities, are also facing a challenge to manage the present and pursue higher levels of life quality. On the contrary, local communities' increased awareness of their identity and uniqueness enlighten small centres' problems of revitalization, also due to a deeper integration of historical areas and buildings in the social and productive life of the local urban fabric.

As for the goals of the implemented solutions, then, no specific distinction can be made, since generally, in all Italian heritage cities or towns all temporal perspectives—past, present, future—are equally present, although with varying prevalence. Then, revitalization and conservation, liveability and planning are homogeneously pursued across different-sized municipalities.

An indirect proof of that is the effort to apply the 'smart' paradigm for the achievement of those objectives, giving life to interesting solutions in large cities (Torino, Firenze, Bologna) as in 'minor' contexts (Benetutti, Città di Castello, Fabriano, Formigine) [104], equally.

Moreover, the recent Italian Smart Cities online platform—an initiative of the Italian Association of Municipalities—shows that project capacities are lively already at all urban scales [105]. The latest "Smart Land" program of ANCI, the Association of Italian Municipalities [106] will strengthen the role of small local municipalities and communities, already among the main drivers of overall Italian development.

Due to structural reasons, a quite different distinction could rather be made among different scale contexts. In this sense, surely small administrations in general, then also heritage towns, suffer, on one hand, from lack of differentiated transportation systems, limited availability of financial and staff resources and specialized skills needed to address the challenge of innovation [103]. Across Europe, they are generally less equipped than large cities to respond to quite similar challenges due to the limited size of their economy [107]. Those differences have direct repercussions on the development of IoT solutions in different application domains, which will be further discussed.

Apart from size-related issues, two other factors influence IoT implementation in heritage cities. The first one pertains to the need to re-think the objectives of heritage projects. For decades, the debate on actions for heritage has been marked by the dichotomy between the physical conservation of resources and their fruition. Such distinction has been naturally transferred to the solutions adopted. As described in the previous paragraphs, the fruition of resources based on inappropriate models has a direct impacts on their physical component. Those impacts add to lacking or poor maintenance (for limited budget at small scales, or for competing priorities within larger cities' policies) as well as to the effects of natural or induced extreme events. With respect to the latter, the former are less disruptive but equally dramatic since they are the results of long-lasting overlooking attitudes towards actions for the built resources. In heritage cities it is then necessary to re-think the objectives of projects for heritage based on a wider concept of conservation.

The second point, directly linked to all the issues described above, relates to the ultimate purpose of development strategies at the basis of the deep technological transformation of urban contexts. In the solutions adopted, the term 'smart' has been gradually replacing the term 'sustainable'. Both in academic debates and in the everyday discourse, the 'smart city' paradigm is acknowledged as enabling the achievement of sustainability, and, according to some definitions, 'smart city' is all about the use of IoT technologies [108]. This seems to suggest that the means has been gradually replacing the end. This association of words leads to losing sight of the content of the sustainability concept and to pursuing 'smartness', in terms of technological infrastructuring, as a value in itself, sufficient to the end. In this way, the assessment of the three-pillars (environmental, social, economic) of sustainability requisites in implementations is omitted.

All the considerations above allow identifying appropriate directions for IoT developments for heritage cities in the Italian contexts. Considering the contextual and structural peculiarities at the different urban scales suggests, within a context-sensitive approach, to propose the coupling of two different elaboration perspectives:

- For heritage towns, simple, low-cost and easy-to-use technological solutions, proven and employing multitasking, appear adequate to cope with the equipment and structural limitations described above. Sensor-based technologies, having already reached a reliable maturity level, have the right potential to abandon the standard use of sectorial solutions (environmental monitoring, structural monitoring, user tracking) in favour of a more complex and complete knowledge of artefacts. In that, multipurpose measurements and surveys can be contextualized, so as to highlight the mutual influences among phenomena. This allows to introduce, underline and measure human contribution also in issues related to physical conservation, resulting in a greater inclusiveness and environmental compatibility of solutions. In fact, the sensor field is already mature enough to support the integration of human-building interaction, transferring it from the domain of user experience (UX) to physical conservation. In this way, users would acquire a higher awareness of the environmental and material effects of practices and behaviour. Mobile phones, sensors, RFIDs (Radio Frequency Identification Devices), actuators have been extensively used and tested in mono-purpose applications. Then, they are reliable enough to support the new goal of both offering visitors personalized cultural content and experience and enabling them to be informed in real time of the effects of their presence and actions on built resources in terms of microclimate and general indoor environment conditions. Bluetooth, suitable for short-term wireless communication, can find its use, for example, in supporting visitors movements within museums or along multi-stop visit itineraries, secure enough for use in the presence of large visit flows, and sufficiently low-cost and low-energy to be implemented in 'minor' or less known cultural sites in small towns or in small museums. ZigBee, appropriate for data transfer on smaller distances, is also a suggested solution, especially to support friendly transferring of environmental information to users, given its spread use for electrical meters and its familiarity to smart home automation;
- For heritage cities, having greater instrumental and competencies capacity, where the complexity of problems is leading towards the spreading of the digital twin paradigm, the inclusion of heritage, in its entirety, as systemic component should be supported, linking it to the study of urban space use patterns. Despite the conspicuous research in this specific city model, heritage does not seem to have received yet its acknowledgment or an effective integration in cities' descriptions, although it represents a fundamental component of the urban fabric and dynamics. Indeed, there is no trace of this issue in major reports on digital twins [85,109–111], or even on IoT technologies, despite their general maturity level, since, to the best of the author's knowledge, no systematic document mentions urban heritage systems, and the built heritage in particular, as specific application field.

> Indeed, despite the high-level sophisticated and impressive solutions elaborated for single sites or collections, the application of IoT to heritage is seen by a part of the research community as being difficult to achieve at the urban scale and from a holistic perspective [59,112–114]. Additionally, in this case, the circumstance testifies an under-exploitation of their potential. Very recent efforts have been made in this sense, although strategies mainly base on the integration of the BIM paradigm, whose compatibility with the concept of digital twin is currently debated [85].

However, specific technologies and protocols appear as more suitable to support solutions for heritage cities, in the sense explained above, than to heritage towns. For example, solutions based on Hypertext Transfer Protocol, supporting strong data communication over networks, can be suitable, while its main limitations – energy cost and expensiveness—can be optimized from within a systemic framework embracing the overall city-scale infrastructure and framework. Furthermore, the LoRaWan protocol, useful in global networks, can be successfully applied in solutions for heritage based on smart-city or digital-twin perspective. Constrained Application Protocol (CoAP), a web transfer protocol specific for use in resource-constrained internet devices, such as small devices with limited CPU, memory, and power or wireless sensor network nodes [115], can become useful in supporting specific tasks to perform on heritage for broad conservation purposes.

Specific importance should be given, in a large urban context, to heritage semantic issues, to support knowledge on cultural resources both for conservation tasks and for personalized and environmentally sound heritage fruition. As for conservation, the relationships of single sites or monuments with their surroundings and with the overall urban fabric can be investigated. As for fruition, semantic knowledge can facilitate the construction of captivating narratives of heritage resources and support the awareness raising of users about the consequences of their urban space use patterns for visit purposes. In this sense, Semantic Web technologies, e.g., Resource Description Framework (RDF) and Web Ontology Language (OWL), should represent key elements.

The digital twin approach finds its sense in large cities, motivated by the large dimension of flows and dynamics, and by the need to reduce their complexity at the risk of losing insights in each specific issue. That same perspective would represent in small heritage towns a useless increase of complexity, that would sacrifice, through the necessary simplification, the peculiar value of towns in respect to cities. This value is represented by the highly personalized and friendly relation between humans and their context, that constitutes one of the main puzzles in digital twins.

Surely there exist instrumental differences between cities of different size, from which useful indications can be deduced. Whereas small towns have to face frequent problems of connectivity and can generally rely on a limited on-site and real-time technical support, cities have their main problems in data volumes and in their management and elaboration.

Certainly, small heritage towns have also fewer financial resources for asset conservation, and since their resources are less known, usually they do not have to manage large visit flows. Indeed, they are also less prepared to absorb the increase generated through promotion activities, and the related potential damages. Surely, they can rely on limited competencies and abilities among staff; then, the solutions elaborated should be simple and low-cost, easy to maintain and with less requirements in terms of technical support.

Heritage towns are, then, the preferential ground for the development of multi-tasking solutions, supporting both tasks of communication/promotion and physical conservation, low-cost and easy to manage. For the same structural reasons, technologies based on visitors tracking are vital for small-sized cultural contexts and museums that cannot rely on external budget.

On the contrary, large heritage cities whose objective is an overall and systemic efficiency can benefit from IoT technologies in a wider application, as is the case with Smart Cities and digital twins. Here, the most appropriate solutions are those aimed at the elaboration of efficient storing and computing technologies for the huge amount of data into play.

Additionally, the conceptual passage from IoT to IoE can be read from two different perspectives: for small towns, to support an individual and organized relation with resources; in large ones, for taking advantage of Big Data, although this distinction is, at the operational level, much more fluid.

At a larger scale in Italy, many museums have been exploiting ICTs for their individual exhibits with excellent results, but there is an incongruence between the inspiring principles of important establishments such as Cultural Districts and Museums Networks, and the practical implementation of this ideal connection. Indeed, the 'network' mode typically pertains to administrative or managerial issues and does not reach the perception of the public, who can generally rely only on museums' individual initiatives and cultural offers. One exception is represented by the "Domenica al museo" initiative, launched in 2014 by the Italian Ministry for Cultural Heritage and Tourism [116], offering free entrance to all museums and cultural sites on the first Sunday of each month, on a national basis. However, this does not imply coordinated actions related to cultural contents The IoT could greatly contribute to the concrete realization of the connection among local cultural resources and their transformation into a real 'system' to present to the public. Specific solutions able to support those two scales are then necessary.

Furthermore, individual institutions such as museums tend rather to collaborate in structural actions, such as equipping or infrastructuring, also through specific financing programs, probably due to cost optimization opportunities. Unfortunately, this collaboration does not extend to the joint definition of interconnected cultural offers. This can be due to understandable reasons of competitive strategies in a period of limited financial support for culture. Nevertheless, a change of approach is necessary, which allows to understand how the connection of possible experiences is, indeed, an effective way to establish a more intense and ongoing relation between heritage and visitors. From this perspective, every visited site can stimulate users to continue exploration elsewhere and discover other resources. In this sense, the diffusion of the IoT can also operate a significant shift in observation perspective of cultural experiences, perceived no more as a definite episode but as a moment within a wider 'sentimental' connection between different publics and the heritage.

4. Discussion and Conclusions

In light of the contextual factors illustrated, the character of current technological advances described in the Background, as well as the directions emerging as more appropriate, allow to outline a multifaceted frame of possible implications and make some reflections.

When discussing the mutual influences between the IoT and the built cultural heritage, we can usefully borrow the PACT (People, Activities, Context, Technologies) model [4] from the user experience (UX) domain in order to categorize the possible implications, although some of them actually affect more areas at the same time.

People—In consideration of the centrality acquired by user experience in the international debate and in implemented solutions, it is appropriate to start by analysing the possible impacts of IoT application to the built cultural heritage on users. Evidently, the connection on the net of devices largely available and familiar for users can contribute to a shift from a strongly individual, though highly customizable, relationship with heritage, to a more 'shared' and collective one. On one hand, this will possibly result in the creation of real communities of site visitors, which can feed themselves through technologies' support also to pre- and post-visit phases. Moreover, the establishment of links among people can potentially favour a more continuous and less episodic relation with heritage. In this view, the conceptual transition from the Internet of Things to the Internet of Everything will certainly offer a theoretical foundation to such development.

On the other hand, with reference to fruition, the spreading of the IoT will result in greater possibilities to facilitate the immersion in the visit context and to support more articulate direct experiences of cultural resources. Through the comparison between current and original human-heritage interaction patterns, users can have the ability to experiment with ancient vs. modern use of the built spaces. Moreover, the enlarged use of common and low-cost devices can provide real-time data on environmental parameters and their variations in accordance with fruition intensity, and on interaction modalities, with a twofold outcome. Indeed, such data will enable users to acquire greater knowledge and awareness about the effects of their behaviours on the visited resources. At the same time, they will deliver management and conservation professionals the information needed to set up correcting actions.

However, another issue must also be considered. This is related to the so-called 'resistance to the system', borrowed from the psychology domain, meaning by 'system' the context where the technological advancement occurs. In this specific case, then, the possible resistance of users towards the adoption and acceptatance of IoT principles should also be considered. At a practical level, this pertains to their actual willingness to make use of devices allowing them to become active parts of global networks. On one hand, the availability of tools for remote control is more easily accepted by end users, such as in smart homes, as they maintain a role of "data utilizers". On the other hand, in the human-heritage interaction, their role becomes twofold, since, to the possibility to use data and opportunities to acquire new knowledge, the role of users as "data suppliers" must also be added, e.g., through the use of wearable devices for movement and behaviour tracking. Undoubtedly, in some cases, the potential spreading is eventually reduced since the need to take along those devices during the visit can be perceived as a burdening or a binding condition or, in an extreme interpretation, even as an intrusion in their freedom to move and behave.

Beyond the time span and site of the visit experience, also the general need to 'stay connected' in everyday life, and the possible unacceptance of those conditions must also be considered. Such unacceptance can be due to privacy reasons or simply to a higher perception of the limitations entailed, compared to the obtainable benefits. Moreover, given the huge diffusion of IoT technologies, it can be reasonably expected that average users can end up feeling 'excluded' from the experiences of heritage if unfamiliar with such technologies or somehow in a condition of 'digital divide', i.e., unequal or poor access to ICTs or to the Internet for socioeconomic reasons [117]. In this way, the IoT, created with the primary potential of inclusiveness, can turn heavily 'exclusive' in fact, if pervasive and monopolizing towards communication modes. On one hand, however, technological advancements are so variegated that it is possible, in theory, to decide what to stay connected for, or not. On the other hand, in practice, it is very difficult for average users to perceive or discern the borders of such faculty. Actually, there is neither full transparency nor sufficient technical skills, among the general public, about interactions, operability and data exchange among different applications. In other words, it is not so easy for users to define autonomously the limits of their own privacy; they 'believe' to choose, but beyond certain limits, they lose sight of the routes followed by data about them.

Activities—Many direct impacts on activities related to the fruition, conservation, communication and management of the built heritage are also exerted by the coming and diffusion of the IoT.

One first consideration refers to museums, already enabled through ICTs to transform their collections from communication 'objects' to 'subjects', enlivening cultural resources in the users' perception. Thanks to the IoT, those same museums now gain the opportunity to turn from simple 'neutral containers' of resources into communication subjects, with unique features. Due to the high connectivity of the IoT and to the possibility to support the explicitation of semantic interrelations among resources, museum buildings lose their 'neutrality' towards their hosted content. The displayed resources being equal, different museums, or the same museum in different occurrences, can emphasize different meanings or facilitate different cognitive paths, as well as realizing different connection frames with the surrounding urban systems. Then, their use of technologies can deeply change the overall significance of the heritage they enshrine in respect to the expected publics and local communities.

Furthermore, this kind of dynamics can be triggered not only in museum management and designing decisions, but also 'from the bottom'. Historical buildings, and architectural heritage in general, are carriers of fundamental values in themselves, in relation to their construction period and to their meaning in respect to it. However, individuals also, through their memories and the specific significance they personally attach to those assets, are carriers of values referable to them.

Then, all those objective and subjective values are complementary and add up together. Overall, the community can give thus a different 'vision' of those assets. The connectivity of the IoT and its semantic support promote participative approaches in which communities re-elaborate such new vision and favour the synthesis of history and memory, and thus encourage the conservation of the sites' significance.

From the point of view of heritage knowledge and information, visitors' tracking, both to deduce their preferences for fruition purposes and to monitor their environmental behaviour and the related motivations for damaging prevention, is also a way to obtain really reliable data. In fact, those data are unbiased by explicit and direct requests of interviewers, as is the case with data from questionnaires and surveys. The usefulness of sensor networks, then, goes far beyond the design of subsequent exhibitions or events. Prior to this, the use of sensors and actuators, clearly allows reducing the physical impact on assets by minimizing the invasive character of conservation actions on delicate built heritage.

Contexts—The structural differences between 'heritage cities' and 'heritage towns' for our country have been previously discussed; given the different sizes of urban heritages, the solutions should be conceived taking into consideration the specific structural features of real application contexts. When fine-tuned against their context and based on a correct identification of their peculiar priorities to pursue, the realizations will have positive effects in terms of liveability, recovery of past values, safeguard of resources' physical integrity, planning of future developments.

Surely also other elements of the national contest must be considered. From a technological perspective, the report of the Polytechnic of Milan's Observatory on the diffusion of the IoT in Italy [118] has put into light how the fastest-growing IoT segment in the country is represented by simple and low-cost applications. We can deduce, then, that a strong, lively and creative and impulse to design will come in the very next years from small heritage towns, enabled to manage smaller-scale problems with smaller budget and means through that kind of tools.

At the regulatory level, the "Industry 4.0 National Plan" of the Italian Ministry for Economic Development [119] identifies three specific action channels in relation to the current and forthcoming investments: instrumental interventions, education programs and the definition of open standards. Consequently, the prospects for the growth of the IoT and the spreading of IoT-based solutions for heritage cities will find positive preconditions if they will focus and connect to those strategies.

Finally, the same plan attaches great relevance to the IoT as the *trait d'union* between information technology (IT) and operational technology (OT). Interpreting this statement in an extensive sense, we can reasonably deduce that the IoT will represent more and more an essential interface in all the processes based on the implementation of knowledge for operational purposes. Then, projects for heritage will also be considered feasible and receive support only on condition that they are built upon the IoT paradigm, which will thus become an inescapable component and design perspective.

Technologies—In operational terms, the IoT is experiencing a transitional phase from a specialized design of implemented solutions (siloed applications) towards a wider and cross-cutting project capacity, with a more integrated vision of heritage. This results in the shift from mono-focus infrastructures to the definition of multi-purposed environments, allowing, through the detection and use of heterogeneous data, for a more complex knowledge of reality.

In line with such general development of technologies, also in this case heritage towns, for which the present article has identified simple and multitasking solutions as the more appropriate ones, they have the most promising preconditions for the success of solutions for heritage.

Moreover, the growing diffusion of devices—sensors in the first place—and data to be managed and processed entails an equally growing need for applications to be developed, in order to cover the full range of their possible uses and optimize the related costs. Significant creativity efforts will be then required of technologies, in order to both multiply the possibilities for dedicated applications and to combine them within multipurpose solutions for the built heritage.

But much more will be required of IoT technology in order to solve two main issues and express its full potential. Although the storing, processing and interoperability of data are currently the focus of a large part of research efforts in general urban-scale IoT systems, the application to whole urban heritages has its own peculiar barriers. In particular, Gaiani et al. [120] underline a total lack of accessibility to specialized information with a prevailing fragmentation of processes.

It must be considered that heritage lifecycle is a process marked by a high level of knowledge stratification, since it involves multifaceted specialized knowledge from a number of domains: engineering, architecture, materials science, physics, history, social science, and others are involved, for example, in conservation activities. Then, one main barrier to a wide application of the IoT to heritage is the difficulty in transferring the relevant information to each different stakeholder. The problem in relation to fruition is even bigger, since the general public also comes into play. Then, while a large part of researchers are currently committed to the dilemma between edge or cloud computing, a shift from data to knowledge management will probably represent one main direction for future research. In this sense, filtering techniques and semantic links could play a role in order to support the creation of the different knowledge patterns required.

Another challenge lies in the marked dynamicity of data and information needed for more effective large-scale event monitoring and risk mapping, which needs adequate solutions. The Risk Map of the Italian Cultural Heritage has been sensibly evolving in the last thirty years, and relies now on a complex systems of interoperable informative systems [121,122]. However, these are largely based on Geographic Information Systems (GIS or webGIS), allowing, to a certain extent, process monitoring and a good level of forecasting capacity, but could further benefit from IoT technologies. Remote sensing is already a reliable practice with reference to structural and environmental monitoring. However, the dynamic nature of man-induced risks is not fully reined, while it could be better managed through a wider integration of available and affordable devices.

The spreading of the IoT in the field of tangible heritage can also have further effects on technologies, with reference to costs. Indeed, it can be considered that, in general, as ICTs become part of wider and more integrated technological systems or infrastructures thanks to the IoT, they can see their specific costs sensibly reduced. In the specific field of museum facilities or large cultural buildings and complexes, this can have a great relevance from the point of view of assignment procedures for the implementation of full-scale IoT-based solutions. In the case of local Cultural Districts or Museum Networks, the interconnection of more museums and of their respective cultural resources will possibly rely on a more definite competitiveness. In fact, businesses or consultants from the private sector can offer, for larger assignments, lower rates, e.g., by reducing the hourly labour fees or taking advantage of scale economies in the procurement of components in large amounts.

Furthermore, the effects on the technological domain can potentially propagate also beyond its strict borders. The need to shift from sectorial applications to wider perspectives for the intrinsic exigencies of the heritage, ranging from more simple applications up to the experimentation of the digital twin concept, will entail also the need for specific professional profiles such as system integrators. This will eventually have repercussions both on the occupational sector and in the education system. Although such impact has a general nature, it acquires in the field of heritage, for the reasons explained in Section 3, a peculiar relevance.

Another important issue to consider in IoT applications to the built heritage is the 'time' variable. We know that very little of the digital information produced decades ago is still existing or useful today, since many of the supports used are no longer available or usable. On one hand, the built heritage is, in terms of both physical consistence and values, a resource to preserve in order to prevent its loss in time. On the other hand, knowledge about it, acquiring value in itself, should also be safeguarded in the same way, in order to transfer it to future generations. Consequently, IC and IoT technologies are now facing the challenge of conceiving storing modalities that survive time; in this sense, and considering the increasing recurrence of extreme events jeopardizing physical heritage resources, their eternity cannot be taken for granted. As we cannot rely on the possibility to digitalize knowledge on a cyclical or recurrent basis, it is necessary that the IC and IoT technological domains define collection and management modalities specifically designed to minimize their obsolescence or unusability.

From a more general perspective, the trend to replace 'sustainability' through 'smartness' requisites in projects for the urban environment and heritage has already been mentioned. This consequently leads to the tendency towards a strong specialization of technological solutions in terms of single goals, sometimes delivering highly refined but end-in-themselves solutions and losing sight of more general and systemic objectives. In order to overcome this approach, as urban contexts are now requiring, and to regain a wider look at cultural and especially built heritage problems, the Internet of Things can bring a paramount contribution. Thanks to its features, it can transform the built heritage of our cities and towns, up to now objects of conservation and promotion actions, in an active urban system, in continuous contact and communication with its users and managers. In the last decades, the international discourse underlined the need to pursue the objective of financially self-sustained heritages, through their ability to attract paying publics. Now the emerging conflicts between local needs for economic development and the necessity to maintain acceptable sustainability levels stress the urgency to operate a balance. The IoT can represent the key factor for this adjustment or 'regulatory' action and deliver the tools to reposition economic growth and sustainability within the right holistic perspective, through a different reading of the tasks of knowledge, promotion, fruition and conservation of the built heritage.

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