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A sustainable approach to tourist signage on heritage trails*

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Abstract: Guiding the visitor to appreciate the sights during an excursion is crucial to building a memorable experience. In the literature, we find many articles exploring the use of sophisticated technologies towards such a goal. The case of tourism proposals for inland areas exhibits a noteworthy aspect, since the presence of human artifacts and the signage may damage the experience, and introduce pollutants as well. This paper analyzes the signage for a natural trail putting into practice a holistic methodology that takes into account all aspects of the problem, starting from the touristic vocation of the area and the social fabric. The analysis indicates slow, community-involved tourism as the preferable target, with extreme requirements of sustainability in the social, economic, and environmental domains for the signage solution. Appropriate governance guidelines are given to implement the proposal. Footprint evaluations address the QR-code technology, which is used to design a real-scale solution finally deployed on the field.

Keywords: Inland areas; heritage trail; digital sustainability; slow tourism; destination governance; community-involved tourism; cultural heritage; holistic approach; QR-code; trail signage

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1. Introduction

Although an official decision is still pending, there is a widely agreed proposal for the naming of the time that we are living as the Anthropocene. Behind this proposal is the recognition that humans have the potential to significantly alter on a global scale the environment in which they live.

The problem with the above fact is that we humans are not able to understand the long-term consequences of deploying such a potential, nor even to keep it under control. Even worse, such capacities are often used with the aim of short-term local effects, ignoring long-term global ones, with the risk of long-term global deterioration. This attitude pervades all activities, starting with the most basic ones as the supply of food and homes, and is often influenced by economic profit.

Leisure and cultural activities, like tourism, bring profit to niche businesses. This creates a reinforcing effect that follows the negative dynamics seen above: a activity that is neutral in itself (e.g., skying) can have a significant impact due to induced effects (lifts) that strengthen the success of the activity (easier to practice) bringing more investment and impact. Unlike the beneficial effects, which are usually well localized, the negative impact has a very broad spectrum that includes environmental, social, and economic sectors, as discussed by Patthey in [1] relating to outdoor winter sports.

To manage this situation, international agencies promote the keyword "sustainability" as a guideline for the conservation of our habitat. Jeffry Ramsey et al. [2] consider the concept behind this word as "vague and disputed but not meaningless" and that cannot be used without a concrete framework, especially in a normative context. To solve the problem

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of measuring sustainability, Tom Kuhlman et al. [3] point out an inherent conceptual tension between growth and stability. This tension has been attenuated by a change in the meaning of the word, which has gone from focusing on preservation for an indefinite future to a concept that includes three "pillars", society, economy, and environment, as determinants that need to be protected in the present to promote sustainable development in the future. The authors relate artificial and environmental goods, discriminating the two cases where a loss in the latter can or cannot be compensated by an increase in the former, introducing the terms of *weak* and *strong* sustainability.

The promotion of cultural heritage, which the Agenda 21 for Culture identifies as a fourth pillar for sustainability [4], is situated in such a complex scenario. As noted by Jorge Otero in [5], local communities benefit from the promotion of heritage: conservation activity generates social growth, while tourism provides an extra income that can be reinvested in promotion. However, just as in the case of ski resorts, there is a risk of compromising the heritage itself. This interaction raises a question of sustainability also for heritage valorization initiatives, two issues that, instead, are often considered in a virtual synergy. As stated in the document titled 'World Heritage and Sustainable Development' by UNESCO [6], calling for actions that "harness the potential of World Heritage properties and heritage in general, to contribute to sustainable development".

This research stems from such a tough contradiction in trying to answer the question: is there a way to unlock the potential of cultural heritage while at the same time limiting the damage to a social, economic, and environmental equilibrium?

The question arises in the course of the Underlandscape project [82] funded by the Italian Ministry of Research aimed at applying cutting-edge technologies to the investigation of karst caves that may have been inhabited, from prehistory to today. Among the expected results of the project is the definition of a strategy to disseminate the research outcomes allowing non-specialists to visit and enjoy the results, thus contributing to the economy of inland areas that are severely exposed to de-population. A sustainable strategy is even more crucial as the geological environment of interest is particularly fragile, as noted by Aleksander Anticc̀ et al. in [7].

This paper illustrates a concrete exercise in designing for sustainability. We introduce an instance of cultural sustainability, an inland region with a legacy to defend, and design a concrete tool to address the issue. To reach fully sustainable result, we need to practice from the early design stages an holistic approach to the environmental, social and financial facets of the problem.

The concrete aspect we address is a signage system, and the solution we propose is based on QR code tags. The result is applicable or adaptable to other environments sharing defined traits.

The next section illustrates signage as a topic of interest. The discussion targets low cost, low impact technologies that are appropriate for outdoor signage of natural or cultural heritage, and finally indicates QR code tags as a consistent technology. The section features a survey of relevant literature.

Section 3 provides the multidisciplinary framework. Section 3.1 illustrates the legacy emphasizing historical facts and locations. Section 3.2 describes the social and touristic context of the target location and provides the guidelines for integrating the initiative in the socio-political fabric. Such guidelines are used to define an agenda, in section 3.2.3, and the section is concluded by a reasoned description of the area, highlighting the points of interest and their reachability **??**.

Section 3.3 describes the concrete implementation that follows the defined requirements. The description of the process to produce the printed tags starting from editable content on a geographic database allows to reproduce and reuse the solution in other contexts.

Section 4 merges the various aspects explored in the previous sections to provide a methodological view of the process, focusing on the interplay between the fourth pillars of sustainability.

(a) CAI mark on a tree **(b)** A direction sign

Figure 1. Signs frequently found on trails in Italy

The conclusive section summarizes the results, the missing parts, and the potential of the solution.

2. Unlocking site potentials through signage

The signage used to guide and inform the visitor is of paramount importance and must be carefully designed to accomplish its functions while following the guidelines of a sustainable approach.

The functions of signage are two:

- an effective signage must guide the tourist across the resort. A map represents a starting point for this purpose, but not all visitors feel comfortable reading a map. The ideal signage should provide visible reference points and suggest actions, like "turn right after crossing the stream". A good example of such signage is the one used by the Italian Alpine Club (CAI), consisting of colored stripes marked on tree bark (see figure 1a). The marks are placed in such a way that standing near one of them, the hiker can spot the successive on the trail;
- a sign should explain the reasons for interest in a site. This generic characterization includes all sorts of semantic characterization of the site, and may have educational or motivational intents. This includes describing historical facts related with the site, as well as advertising nearby points of interest (see figure 1b). In this sense, the CAI signal above is not sufficient. A simple board with a site name fits only when the site is sufficiently popular. Otherwise, a more structured message should be used to pursue an educational intent.

In our study, we consider a range of solutions that support sustainable tourism, specifically the dynamic provision of information during a visit along a natural trail not covered by Internet connectivity. We consider the presence of two stakeholders for the signage itself [8]: the hosting organization (the *host* for short) which implements a signing installation, and the visitor (or *user*) which extracts useful and enjoyable information from signing devices.

The purpose of such an installation is guiding the *user* on a tour that includes urban streets, buildings, natural trails, and caves (this latter being the topic of the project giving financial support to our research). The task of the *host* organization is to provide the *user* with all sorts of information that may guide him across the visit, making it as profitable and enjoyable as possible.

A traditional approach makes use of physical information boards with graphical or textual content, as in figure 1. Our study starts by pointing out the issues related to such a solution:

- dimensions: the board must be sufficiently large to contain the desired content, taking into account its readability from a distance;
- installation logistics: depending on the location, the transportation and placement of a plaque may require a basement or other sorts of supports;
- environmental impact: to be effective, the plaque has to be prominent, and this may negatively affect the quality of the site;
- accessibility for the visually impaired: the plaque is not useful for visually impaired persons;
- accessibility for foreign visitors: to limit the size of the plaque, the number of translations must be limited as well;
- update limits: to update the content, the plaque must be replaced;
- removal logistics: when the board degrades it must be either removed or replaced, which entails waste disposal together with other issues similar to those found during the installation.

Such points motivate an investigation to find alternative ways.

2.1. Technology to minimize intrusion

We characterize our approach as an instance of *weak sustainability*: we do not preclude intervention in the environment, but the impact of such intervention must be better than that related to traditional signs. To this end, we include in our solution tools that are not part of the site but remain with the user.

During the last decades, we witnessed the diffusion of smartphone devices, and we have no reason to expect a change in such a trend. Smartphones enhance the communication capabilities of individuals by allowing them to receive sound, visual, and tactile interactions. The relevance of such capabilities for the improvement of a tourist experience has been widely investigated, either in urban environments [9] or in a rural milieu [10] to find ways to exploit such tools. As we did with physical information boards, we highlight the limitations of this technology, particularly when it comes to outdoor activities.

One is that smartphones although widely available, are not equally familiar to everybody. This is related to *usability*, with a term borrowed from P. Wan in [8]. The second is that several functions depend on the provision of enabling services: for instance, their networking capability is useless if the device cannot reach the Internet. So the *applicability limits* of a solution need to be defined.

Starting from the two aspects above we envision the guidelines for a successful smartphone-based strategy, keeping in mind its sustainability.

Regarding *usability*, the basic recommendation is to keep the operation within the experience of the majority of users, without requiring them to familiarize themselves with new applications.

The definition of its *applicability limits* is more complex, especially for outdoor activities. In such cases, the provision of a networking infrastructure incurs a severe environmental impact. Consider the installation of antennas to cover a wide area and the power supply for the radios.

2.2. Related works

The research literature marginally covers the utilization of smartphones for tourist signage purposes.

An exhaustive solution is described by P. Liu in [9], which details an infrastructure that guides the visitors inside an urban milieu. In that case, the presence of pervasive networking facilities is a cornerstone for the whole architecture, which deeply depends on Internet connectivity.

Wan [8] evaluates the quality of signage, without referring to a specific technology, but with many examples showing physical boards, using as a formal reference the Universal Design Principles [11].

The number of research papers explodes when we extend the range to articles investigating smartphones' impact on tourism. The *smart tourism* topic is very popular, and covered by several review papers that provide a framework to the vast literature.

A popular research direction covers the social aspects related to the use of the smartphones. W. Tan [12] covers all aspects of a touristic experience related to the smartphone, from the definition of travel destination to assistance during the visit. Much attention is dedicated to the network of connections that is established thanks to the smartphone, which, again, is considered on the Internet. Such an assumption is in contrast with the title, which indicates a nature-based destination, where notably the Internet is not always reachable.

On the other hand, roaming in places not reached by the Internet, or *dead zones* using the term introduced by Pearce and Gretzel in [13], may evoke contrasting feelings, from rewarding to threatening.

More recently, the smartphone has been considered not strictly related to communication. In 2021 A. Slavec et al. investigated the use of cameras [14] while on travel in locations with a relevant cultural heritage to sustain its preservation and engage the tourists using location-based games, similar to Pokemon Go or geo-caching.

In 2023 V. Rodrigues et al. published a systematic review of papers considering the interrelationships between tourism and portable digital devices [15]. Although the title evokes a one-way contribution, i.e., the impact of digitalization is assumed to be positive on the quality and the sustainability of touristic offers, in the conclusions the authors reveal the awareness for the need to address *"the preservation of tourism attractions/sites"* and call for a *"a holistic approach ... to support a concept that still lacks conceptual and empirical clarification"*.

In that direction, we meet the phenomenon of *overtourism*, covered by significant literature reviewed by Dodds and Butler [16], which focuses on urban tourism and its social consequences. The impact of *overtourism* on resorts that trade on their natural resources is investigated in the case of the Hawaii Islands [17] or Costa Rica [18] stressing the impact on the social fabric.

The present paper wants to fill the gap highlighted by Rodriguez, providing a conceptual yet pragmatic approach to a well-defined aspect of tourism support, taking into account its sustainability "by design". Once a range of relevant solutions is identified, we proceed to the empirical part: a *proof of concept* implementation that verifies the feasibility of a specific solution.

Regarding the specific technology we refer to, QR codes have been invented in 1994 for industrial applications. The current version, described in [19], is dated February 2015. In 2013 an early paper by Martinez et al. [20] suggests its utilization to implement a virtual tour in the *Las Quilamas Natural Park* in Spain. At that time the availability of QR-code readers was not as diffused as today, and therefore the work may be considered among the seminal ones. The authors proposed to use the QR code as a link to a panel in PDF format viewed on the user's portable device. A similar work in a urban environment is presented in [21] and [22], the latter illustrating the QR system serving the monuments in the Serbian town of Niš.

Since then the use of the QR code technology for heritage promotion has been suggested in other papers. In [23] the authors describe its application in a museum: after defining the points of interest, tags have been placed and linked to related documents. The authors conducted a poll about user perception on two segments of users: Italians and Polish. The QR tags were not unanimously considered useful: in particular half of the Italian users considered them as not useful. It is interesting to note that the motivation of the other segment of users, less skeptical about usefulness, shared a solid educational motivation to access QR-linked content (70% in the Polish group against 50% in the Italian one). This fact sheds light on the necessity to provide content the user needs: curiosity is not a sufficient motivation.

Recent publications about the use of QR codes for heritage valorization do not show significant novelties. In 2023, the authors of [24] introduce the installation of six QR codes

in a museum and analyze the reactions of 42 visitors. The tags are created using the Taplink https://taplink.at/ web service and are linked to content on the Web.

There are examples of urban outdoor applications of QR tags, like

All the found publications share a common attitude, which can be summarized in the motto "analog portal to digital world", as in the title of [25]. None of them evaluates the possibility of storing text in the tag itself, thus eliminating the requirement of an Internet connection.

The present paper promotes the use of QR codes with sustainability and as the primary or only way of providing information to the visitor. In the literature, QR codes are considered ancillary to other forms of communication, like physical installations or the Web. Therefore, in our case the informational content of the tag, which is commonly ignored, becomes relevant. It is a new and original way of using QR codes for the delivery of information.

We emphasize that this article is not meant to quantify user satisfaction or the economic revenue associated with the specific solution. Such a target is outside the scope of our research, and indeed the figures that would measure the success of a strategy deserve a thorough investigation. We aim at isolating an issue, proposing a sustainable strategy for its solution, and implementing a proof of concept for it.

2.3. A simple, low-impact solution

The wireless capabilities of a smartphone are the focus of a straightforward approach. Given the premise that the Internet is assumed to be unreachable, the *host* stakeholder might provide a local network of low-power radios covering the region of interest. Small servers connected to the network would host specific Web services. The approach requires a modest investment and a marginal environmental impact: for instance, a small device based on the ESP8266 single-chip computer (SCC) has a coverage of tens of meters, and a volume in the order of the cm^3. It can provide a WiFi Access Point as well as Web content. The ESP8266 has a capacity of 32KB, which is sufficient for explanatory text and a low-resolution image. Other SCCs, like the ESP32, are more powerful but exhibit a higher power consumption.

Such a solution is severely limited by the dependency from a power supply. A radio transmitter is a rather power-consuming device, in the range of Watts. Even if intermittent, the operation of a battery-operated networking device cannot be guaranteed for long periods and the host organization should consider power harvesting, which negatively contributes to the economic cost and environmental footprint of the device.

For this reason, we do not consider a solution based on the deployment of a networking facility as a valid competitor against traditional board-based design. As explained, the reasons are related to poor sustainability.

An alternative consists of the utilization of passive devices, like Near Field Communication (NFC) transmitters. The transmitting device is flat, the size of a coin, and costs less than one dollar per piece. To receive the content the smartphone must be very close to the NFC tag. The power needed to operate the radio is drained from the smartphone so that the transmitter does not depend on batteries. The NFC device capacity is in the range of the KBytes, nearly a page on this journal. Engraving content onto an NFC tag is a straightforward task that requires a smartphone and an ad-hoc app.

The NFC technology is available without installing ad-hoc applications. Its operation consists in approaching the smartphone to the tag, and the user is advertised that a content is available. The smartphone can read it aloud to compensate for the user's inability or translate to deal with linguistic issues. Such capabilities do not need an Internet connection but currently depend on ad-hoc applications.

Another solution in the family of passive devices is the QR tag (QR stands for Quick-Response). Such a technology does not require radio communication but uses the smartphone camera to acquire text encoded in a graphical code. The capacity of a QR tag depends on the number of dots in the image, which in turn depends on the size of the code and the

Figure 2. An NFC coin, a QR tag used in the prototype, and a 1 Euro coin by comparison on a paper with a square of 1cm

smartphone camera characteristics. We may consider that the capacity of a QR tag roughly equals that of an NFC tag. A QR tag is larger than an NFC tag of comparable capacity, and manufacturing requires a printer.

A preliminary check verifies compliance of the passive technologies described above with the Universal Design Principles [11]:

- *Equitable use* is closely related to the smartphone technology, which is itself considered a vehicle for equitability,
- *Flexibility in use* is enabled by the device capabilities, which allow listening instead of reading, translating the information in a different language, or storing it for later use,
- *Simple and intuitive use* holds since the operation requires a single application, possibly already installed since useful in many circumstances, and tag reading requires a single finger touch on the smartphone,
- *Perceptible information* is a critical requirement, which contrasts to keep low environmental intrusion. This point will be further discussed in the section devoted to the implementation,
- *Tolerance for error*: there is no chance of accidentally causing a hazardous situation using the QR tag. The unintended release of the passive device into the environment determines a minor pollution,
- *Low physical effort* holds, although the user needs to carry a smartphone,
- *Size and Space for approach and use* need to be carefully considered. In the case of the NFC tag the smartphone needs to be nearly in touch with the passive device, while the QR code must be in the line of sight and frameable without effort.

Compared with other smartphone-based technologies, there is a trade-off concerning capacity. However, a signage applications a capacity of 2-300 words is sufficient to provide directions for the visit and convey text-based educational contents. If capacity limits are not an issue, a solution based on NFC or QR tags exhibits several advantages:

- does not require power supply,
- has a limited impact on the landscape,
- does not entice theft,

- has a negligible cost,
- is durable,
- produces a limited quantity of waste when disposed of,
- content can be stored for later usage; for instance, to visit a URL once the user reaches a zone covered by the Internet,
- is inclusive regarding user inabilities and nationality,
- requires basic technical skills from the user.

The two passive technologies of choice exhibit the following features, that may make one of them preferable for a specific application:

- an NFC tag is smaller than a QR tag;
- writing an NFC tag requires a smartphone, while the QR tag needs a printer;
- reading an NFC tag works near-to-contact, while QR tags can be read from a distance;

For a signage application, a QR tag is preferable because a noticeable size is needed. In addition, keeping the tag out of reach prevents vandalism and misuse. Therefore we have reasons to select a QR-tag-based solution for smartphone-based signage.

Its use is especially appropriate when the cultural heritage extends across a scarcely accessible land, preserving and accessing sites located on private property or in hazardous areas can be challenging. In these cases, QR tags could improve the visitors' experience by providing, besides textual data, the Web URLs for videos, aerial shots, and photos. Multimedia resources allow visitors to immerse themselves in the area's history and gain an experiential understanding, even if they don't have access to a specific spot. The resulting widespread knowledge can be a beneficial tourist-economic engine that encourages investments in cultural heritage policies, thus achieving the goal of protecting and conserving abandoned sites.

We now examine how such technology copes with the limits of a traditional board-based approach (as listed in table 2):

- dimensions: a 2-300 characters QR-code has a dimension in the order of 100 cm^2
- logistics: QR-code board can be installed on any sort of pre-existent or natural support
- impact: the board has minimal interference with the landscape and may easily go unnoticed
- accessibility for the visually impaired: the text can be read aloud
- international: the text can be translated automatically
- update: the board can be easily replaced when the content becomes obsolete
- disposal: the card releases a limited quantity of pollutants related to ink support (paper or plastic)

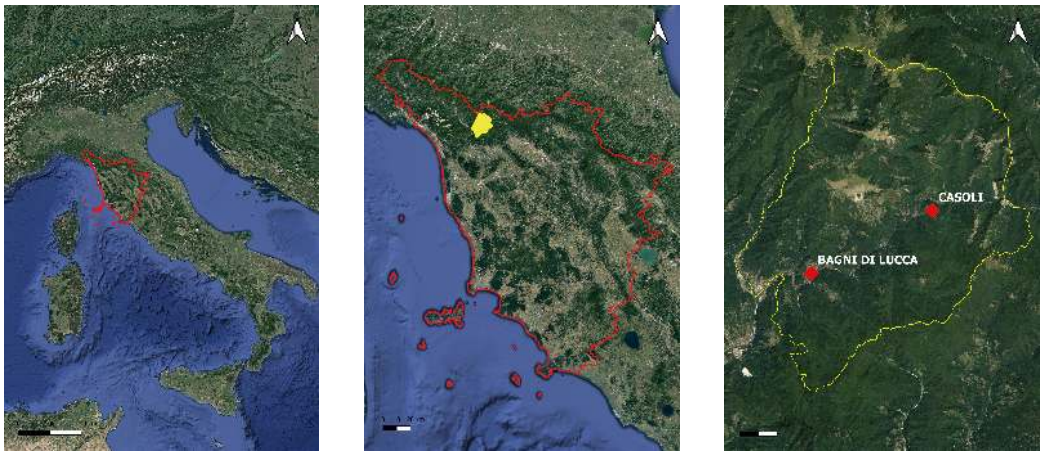
The host needs to resolve two issues. One problem is the balance between visual impact and visibility. Monitoring tag utilization, which is useful for all types of planning activities, is the other topic. They are discussed in section 4.

3. Materials and Methods

Our study aims to demonstrate a sustainable solution in a concrete setting through a proof of concept. In order to follow a holistic approach, we must start with the definition of the operation framework.

This section is dedicated to describing the economic and social context, as well as the historical background that characterizes the heritage resource we want to promote.

The geographical area of interest is the surroundings of *Casoli*, a small village in a mountainous region in the north of Tuscany, Italy. The area falls within the municipality of *Bagni di Lucca*, in the province of *Lucca*. In 2021, the archaeological team of our project realized a thematic map assessing the reasons of interest for the heritage and the geomorphological features of the area.



(a) Italy and Tuscany, bordered in red

(b) Tuscany and the municipality of *Bagni di Lucca* (in yellow)

(c) Location of the *Casoli* village in the *Bagni di Lucca* municipality, bordered in yellow. The small town of *Bagni di Lucca* is visible located a few kilometers west of *Casoli*

Figure 3. The region of *Casoli*

3.1. The natural and cultural assets of Casoli *and its vicinity*

Bagni di Lucca is located on the north-eastern boundary of the Province of *Lucca*, in *Val di Lima*, and is part of the *Media Valle del Serchio* district. With its mountains it marks the historical border with the *Modena* and *Pistoia* area, it is very rich in potential for its naturalistic, archaeological, and historical heritage, both expressed and as yet unexpressed. Thanks to the archaeological map the main sites of interest from prehistoric to contemporary times in this municipality are cataloged, photographed, and georeferenced.

From a historical-geographical point of view, this area is identified with the *Lima* stream and its tributaries, which impress the area with a peculiar geomorphology impervious despite the modest hilly elevations.

The *Lima* stream has characterized the history of *Bagni di Lucca* since ever: the valley's ancient river terraces contain some of the earliest evidence of human presence, such as caves and rock shelters frequented since the Palaeolithic age; the manufacturing industry (paper mill, flour mills and, in recent times, energy production) have exploited since the Middle Age until the 1980s [26–28].

On the naturalistic side, the region of *Bagni di Lucca* encompasses an incredible concentration of biodiversity, counting no less than three sites of the Natura 2000 Network [69] European Economic Community (EEC) initiative.

There are three SCIs-SACs (Sites of Community Interest and Special Areas of Conservation) located in the area north of the *Lima* stream, corresponding to the Apennine portion, covering 23% of the municipal surface:

- the limestone areas of *Val di Lima* and *Balzo Nero*;
- *Monte Prato Fiorito-Monte Coronato-Valle dello Scesta*;
- *Orrido di Botri*.

The latter is also a SPA (Special Protection Area) and the *Orrido di Botri* State Reserve is located within it [69]. It is therefore a natural heritage with a fragile balance that needs to be preserved.

In recent years, the main tourist attractions have concentrated on the *Lima* stream, with some associations and private entities promoting outdoor experiences, particularly fluvial sports, such as canyoning, rafting, and paddleboarding. Other important tourist

attractions are trekking and hiking, supported by a network of paths tracked by local CAI (*Club Alpino Italiano*).

In the last few years, the community opened two entirely new trails:

- the *Alta Via dei Pastori* (2019), a ring around *Monte Prato Fiorito* that takes up the ancient grazing route, and
- the *Sentiero degli Avi* (2020), a ring that from *Montefegatesi* reaches *Monte Coronato* [29]

Another recently developed project (2019) is the expansion of the Saint Bartholomew's Path, which runs through the territory of *Pistoia*, with a variant that from *Popiglio* continues in five stages in the municipality of *Bagni di Lucca* to *Pieve di Controne*, acting as the '*Lucca* gateway' to the Path [85].

Such initiatives led to a considerable revival of interest among Italian and international hikers in the area, especially for the Apennine side of the valley.

The way to improve the valorization and enjoyment of this area applies to a slow tourism approach. This approach can involve the community, especially in the southern part of the municipality, which is still less frequented, more hilly, and therefore less traveled by the network of trails. We envision the creation of geo-itineraries characterized by the rediscovery of the historical roads, partly well-preserved, which connected the villages with the valley bottom and between them, including those sites of interest that encapsulate the history of this area, starting with the caves.

3.1.1. An historical perspective of an Italian mountain site

This section outlines the historical framework that explains the selection of QR tag locations and their associated content. It is based on previous archaeological and historical investigations. The sites mentioned in the narration can be found among the QR codes listed in table 2.

The village of *Casoli* is located south of the *Lima* stream on a hill named *"Tanette"*. In the local small lair, the name reveals the presence of karstic cavities, some inhabited between the Paleolithic and the Iron Age and used also as stations on the trans-Apennine routes [26,30–33].

Ceramic fragments dated between the 3rd century BC and the 1st-2nd century AD prove that Ligurian populations occupied the region scattered and in small nuclei. The dedication of the Latin colony of *Lucca* in 180 BC marked a decisive turning point in the Romanisation of the area and, shortly after, the definitive subjugation of the Ligurian populations, accompanied by a rapid acculturation [30,34].

We have little evidence of Roman settlements in the mountainous hinterland, and the scarce archaeological traces are concentrated in the cave of *Buca La Piella*, investigated in 1975 by the Centre for Archaeological Studies of *Lucca*; it has two entrances joined by a walkable tunnel and rooms of discrete dimensions that overlook the outside. In addition to numerous faunal remains and fragments of locally produced common pottery, twenty bronze coins belonging to the 3rd century AD, bronze and lead objects were found [30,35,36].

In Longobard and Carolingian times, *Lucca*'s *Val di Lima* was one of the three administrative districts into which the mountains were divided and was called *fines Contronenses* [37–39]. The only find from this period is the *Grotta di Arzale*, a rock shelter that opens up northwest of *Casoli* [30].

The first attestation of the settlements of *Casoli* and *Lacu* dates back to the 10th century [30]. Most documents of this period show the fractioning and alienation of ecclesiastical heritage in favor of the city aristocracy, securing an accumulation of funds and power that was to form the basis of the subsequent domains [30,37,40,41].

Written sources mention a castle in *Casoli* from 1180, but its foundation must be earlier. Between the 13th and 15th centuries, the fortification was at the center, along with the other castles of the *Val di Lima*, of clashes between *Lucca*, *Pisa* and *Firenze*, with alternating fortunes, as it was a strategic border area for the power of *Lucca*. Today, very little is preserved and the area is partly inhabited [30,40,42].

The same document from 1180 mentions the church of *San Donato*, located in the main square of the village of *Casoli*. The current structure dates back to the 12th-13th centuries, with subsequent renovations. Initially dedicated only to *San Donato*, it acquired a double dedication after the abandonment of the church of *Sant'Andrea de Lacu*. The latter is located on a plateau to the east of *Casoli* lake and is attested from 1260 [30,43,44], but we are aware that it was abandoned in the 15th century. [30,45]. This was probably due to the depopulation of the lake area and the simultaneous strengthening of the town of *Casoli*, which was fortified and better protected during this unstable period.

Today, the Romanesque church of *Sant'Andrea de Lacu* is in a state of decay, with a rectangular plan, ending on the east side with a semi-circular apse. Inside, there is a reused element of the previous building, testifying to an older origin, probably contemporary with the ancient settlement of *Lacu*, meaning "lake" and mentioned in sources from the 10th century and no longer visible today.

In the early modern age, villages of the area experienced a progressive architectural renewal, which still largely characterizes the settlements today. Within *Casoli*, a series of residential buildings with imposing dated portals are preserved, some with courtyards, and mansions that denote a discrete deployment of resources by wealthy social classes. Also dating from the modern era is the *Madonna di Castello* oratory, characterized by an entrance enclosure and located along the cobbled road that traces the ancient route between the village and the summit area of the medieval castle [30].

Along the road that led toward *Lucchio* crossing the area of *Casoli* lake, there is the chapel of *Madonna di Col di Piano* and two "*metati*", buildings destined for chestnuts drying, referable to the contemporary age. Referred to as the "bread tree," chestnut fruits and the flour derived from them were a staple of the mountain diet until the mid-1900s [46,47].

3.2. An integrated view of tourism in the Casoli *region*

The relevance of the touristic context of the territory is crucial in understanding the socio-cultural system of potential tourist destinations. In light of this and for a holistic study approach to social features of tourism, the host and traveler relationship is directly related to local development and local government systems [48]. In this study, the perception and community empowerment in local tourism are crucial for future destination planning. On the socio-economic hand, it is fundamental to understand touristic data and indexes which are specifically related to *Bagni di Lucca's* tourism dynamics, as the administrative land hosting *Casoli*. In this perspective, the following paragraph concerns Bagni di Lucca's demography and touristic data analysis that will be depicted for local sustainable governance measures.

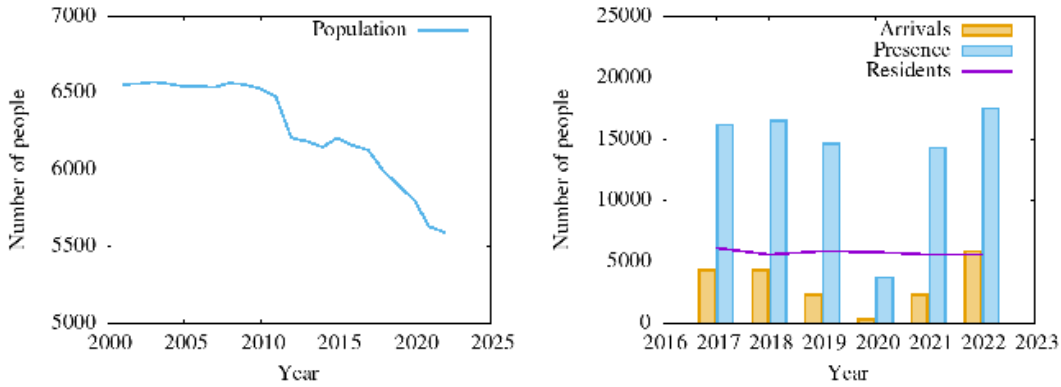
3.2.1. Tourism dynamics in *Bagni di Lucca*, the *Val di Lima* and *Casoli*

In Italy, a municipality is the smallest geographical-administrative unit offering accessible data about tourism, which are the fundamentals of our research.

Bagni di Lucca owes part of its charm to the river *Lima*, which runs along the city before flowing into the *Serchio* River. The *Lima* Valley (*Val di Lima* in the local idiom) is a touristic basin set in the *Serchio* Valley, dotted with medieval and Roman villages with historical remains such as underground caves. The *Val di Lima* area is well-known for its environmental beauties including rupestrian and lake ecosystems, and offers a wide range of tourist attractions related to sports, from water sports, such as canyoning and rafting, to trekking in water and land, climbing, mountain biking, and horseback riding. Overall, the *Val di Lima* has the capabilities to promote a very identifying destination brand straddling the town of Lucca and the mountain area of the *Garfagnana*.

The strategic position of *Bagni di Lucca* is one of the strengths of its tourism context, together with the presence of such attractive elements like the *Orrido di Botri* [84] with the *Canyon Park* [89], and other service companies and associations for experiential tourism.

In reason of a whole insight of the mentioned touristic area, a socio-cultural approach is needed, by considering also tourism flows. In this perspective, it must be considered



(a) Population trend (2001-2022) **(b)** Tourism flows and population (2017-2022)

Figure 4. Demography and tourist flows in the municipality of *Bagni di Lucca*

Region	Bagni di Lucca	Lucca
Resident density (residents/km^2)	33.95	215.71
Touristic density (visitors/km^2)	106.41	1866.96
Average stay (days)	2.98	3.36
Accommodation density (accommodations/km^2)	10.14	19.30
Coexistence (100 × Foreign/Italian)	103.74%	69.87%

Table 1. Tourist indexes in *Bagni di Lucca*

that there isn't touristic information at the administrative level of *Casoli*, so the tourism context analysis concerns the Municipality area of *Bagni di Lucca*, as the first territorial context providing tourist data registered by ISTAT (National Statistical Institute) [63]. The demographic trend (Figure 4, a) enlightens a relevant aspect of *Bagni di Lucca* society and economic aspects of its touristic ecosystem (Figure 4, b).

Bagni di Lucca stretches on 164.70 km^2 area with a population density of 33.95 inhabitants per square kilometer and a job occupancy rate of 33.53%. Regarding human growth at the territorial level, it is relevant to consider the *Bagni di Lucca* population trend during the 2001-2022 period. The curve shown by figure 4a registers a constant and slight decrease of one thousand people in a twenty-year time frame (2001: 6556 people; 2022: 5593 people).

During the latest decades, numerous touristic operators have started their touristic activities by taking advantage of the climatic and morphological characteristics of the territory. From a quantitative perspective, it is relevant to understand the tourist flows during a 5-year time frame; the chart in figure 4b highlights a decreasing trend from 2017 to 2021 by considering the pandemic breakdown impacts on tourism.

The Tourism Density Index is the rate between the number of tourists and the surface area in the higher touristic season. It is 106.41 tourists per km^2 in 2022. The arrivals exhibit a drop from 2019 (from 4339 in 2017 to 2363 in 2021), and touristic presences have suffered a slight decrease during the same period, as shown in figure 4b, while a further increase has been registered in 2022 (5.876 arrivals).

The touristic area of *Val di Lima* features a tourist area belonging to *Bagni di Lucca* Municipality, the second touristic area after *Barga*, in the *Media Valle del Serchio Area*.

Table 1 provides statistical data concerning tourist flows and accommodation in *Bagni di Lucca*. Notably, the tourist density of 106.41 tourists per km^2 is higher than the population density (33.95 inhabitants per km^2). This information should be considered in local planning to enhance the number of residents.

As shown in 1, the number of nights per tourist amounts to an average of 2,98 nights per tourist during a year and it is also significant since it shows, on one hand, *Bagni di Lucca* context appeal for tourists choosing to stay a number of nights more than a weekend and less than a week. On the other hand, this data means that people like staying in this tourist

comprehensory and they may have found attractions, services and activities they need. Consequently, a well-organized touristic system attracts potentially touristic presences widespread on the municipality territory.

The coexistence index describes the distribution of tourist nationalities: 103.74 foreign tourists per 100 Italians in *Bagni di Lucca* indicates a significant share of foreign tourists.

For a benchmarking point of view, the provincial touristic context of *Lucca* is mentioned in this study with the purpose of highlighting the percentage weight of *Bagni di Lucca* tourism flows within the whole tourism dynamics of the Province of *Lucca*. As concerns tourist indexes shown in Chart 3, the touristic density counts 1866.96 people per square kilometer (1773 km^2), with an average stay of 3.36 nights per tourist, showing a medium-length permanence in the provincial territory; this data is in line with *Bagni di Lucca* average stay (2.98 nights). The provincial area of *Lucca* shows an accommodation density of 19.30 on 10.14 of *Bagni di Lucca*, while the coexistence index of *Lucca* (with 69.87 foreign tourists on 100 Italian tourists) is lower than *Bagni di Lucca*'s coexistence index (with 103.74 foreign tourists in 100 Italian tourists). Definitely, it can be claimed that *Bagni di Lucca* is well positioned in the whole touristic context of *Lucca* since it represents one of the less populated municipalities in the territory with interesting tourist indexes. In fact, *Bagni di Lucca* boasts its historical thermal tourism tradition together with a well-equipped environment for sport and adventure tourism, on a surface of 164.70 km^2, that is one of the biggest municipality areas in the province of *Lucca*.

Several promotional websites advertise Bagni di Lucca attractions such as these two destination websites: www.turismobagnidilucca.com and www.valdilima. org; the sitography closing this paper contains a long yet incomplete list that confirms such a statement.

From the point of view of our research, the context of Bagni di Lucca helps to understand the complexity and variety of mixed tourism clusters (a sort of "touristic ecosystems" with common identitary elements such as: anthropic, socio-cultural, and historical features, as well as touristic services). Indeed, Val di Lima can promote a very identifying destination brand straddling the town of Lucca and the Garfagnana mountain area. The Municipality of Bagni di Lucca and the tourist area of the Val di Lima are the context for the small and fascinating village of Casoli, which is one of the 31 villages belonging to the Municipality. It is 7.22 km far from Bagni di Lucca, at an altitude of 500 meters.

Casoli village boasts a heterogeneous range of tourist attractions, including both soft and hard outdoor experiential activities, such as: canyoning, rafting, and trekking experiences in the Canyon park. Additionally, it features Romanesque churches and huts attracting visitors looking for various experiences such as thermal, environmental, outdoor, sport and cultural activities. Throughout the year, local stakeholders offer a variety of services, often incorporating sustainable tourism practices. After a detailed analysis of the tourist and social context of Bagni di Lucca, it can be claimed that the area boasts a good tourist appeal towards Italian and foreign tourists searching for various kinds of touristic experiences [49] dating back to the '90s, when some associations [87–97] began organizing mainly trekking excursions and rafting experiences .

As part of Bagni di Lucca's ecosystem, with its focus on tourism, Casoli is a destination for slow travel. It is important to ensure that any development actions taken are sustainable, in order to preserve its unique social fabric. This means paying attention to conservation of the environment and cultural heritage, as well as preserving intergenerational continuity and economic equity [3].

3.2.2. Guidelines for a sustainable development

As described by [50] Dianne Dredge and in light of the above analysis, private and public entities can contribute to sustainable tourism by developing the following actions:

- Public actions:
  - to foster an inclusive stakeholder approach for the tourism ecosystem
  - to promote a *community-involved tourism* vision
  - to monitor and analyze tourism flows

  - to plan a *slow tourism* development strategy to achieve environmental, cultural, and socioeconomic sustainability objectives
  - to develop digitization tools and strategies for culture and tourism fruition
- Professional actions:
  - to renovate experiential tourism with a sustainable approach
  - to develop potential touristic areas with unexpressed tourism appeal
  - to diversify tourism offers based on tourist provenance and service preferences
  - to monitor tourism flows and tourist behaviors
  - to foster a public-private collaboration approach to use public funds for tourism and cultural projects toward sustainable objectives

The above-mentioned tourism and culture measures should be included in a wider and holistic planning vision for *Bagni di Lucca* as a heterogeneous cultural and sustainable destination. The combination of private and public interest as a long-term strategy for a comprehensive tourism approach needs a bottom-up vision involving residents and local operators in tourism and tourism-related sectors [51,52].

In this way, *community-involved tourism* can be a promising solution for sparsely populated areas with significant tourist attractions, such as the village of *Casoli*. This type of tourism involves active participation and entrepreneurship from the local community to promote self-employment, community management, and stakeholder decision-making processes [53].

In order to create a successful strategic plan, it is crucial to have a thorough understanding of the destination's morphology, environment, history, culture, society, and economy, with sustainability being the key value. Policymakers should recognize such needs and act in this way, both politically and socially as described by Beatrix et al. in [54]. As concerns the empiric case of *Casoli* village, within the wider context of *Bagni di Lucca*, tourism is a key driver for re-population and re-qualification strategies, mainly where historical and archaeological sight can be promoted with natural attractions.

In such a context digitalization plays a primary role in innovation actions, allowing effective monitoring of tourism dynamics, improving the touristic experience with geo-localization tools, and providing the tools to design and operate tourism initiatives [52].

3.2.3. Our activity

We include three stakeholder communities in the evaluation of the response to the initiative. We do not speak about *success* since the initiative is deliberately soft, an outcome expected in years, and the definition of the evaluation criteria raises new questions. We are content with determining if the stakeholders viewed the initiative as intrusive, helpful, or simply neutral.

We considered four stakeholder communities:

- *the residents* the local community that currently inhabits the site
- *the entrepreneurs* who currently have a business on the site
- *the administrators* that are in charge of managing the site resources and that, at due time, will respond to the two stakeholders above, and finally
- *the users*, those that come to *Casoli* to visit the Cave of La Piella and that we find the QR-codes on their way

The QR tag does not record reading operations, preventing an evaluation of the user category. A URL was added to the text message in the QR tag to monitor the number of hits.: however, this feedback largely underestimates the number of times the tag is read.

Considering that each stakeholder category has specific concerns that need to be addressed, our focus has been on understanding the unique characteristics of each category, including their needs and expectations for tourism and environment development.

Regarding residents, we had the chance to meet a few people living in *Casoli*, which did not provide useful information; local entrepreneurs we met informed us about the

trekking tourism flows passing through *Casoli* and the Piella Cave path, which usually starts from the Canyon Park experience.

The administrators of *Bagni di Lucca* Municipality were highly involved in addressing the study's concerns and provided valuable information regarding archaeological and cultural aspects that align with our study goals, namely to enhance *Casoli* area as a sustainable area for hi-tech oriented tourists.

In light of the above assumptions, a reflection on *community-involved tourism* perspective is needed. As shown by this empirical study, a small village like *Casoli* can require a valorization strategy taking advantage of the wider local tourism context.

According to a holistic development vision, when a tourist destination meets its community issues it means that local stakeholders must balance a tourist industry vision with sustainability goals at a comprehensive perspective on the environment, socio-cultural and economic long-term benefits, as described by George B. Et Alii [55].

Indeed, a multi-stakeholder approach could represent a valuable tool for "minor tourism" and well-established tourist destinations.

Literature on this scientific focus, as described by Richards G. and Derek H. [56] gives evidence of local stakeholders' role as 'designers' of their living territory. This is particularly important in inland and marginal tourist areas that require a sustainable approach to development, rather than relying on mass tourism.

A systemic vision is necessary to manage these areas effectively. With these concerns, inner area governance needs a sustainable-led community and policy approach considering socio-cultural local aims for tourism system implementation and environment development. In these terms, local awareness is fundamental for private and public stakeholders enabling sustainable decision-making processes.

On the pragmatic hand, the scientific aim of our territorial exploration is to promote cultural and tourist points of interest with high tourist value. In this regard, we have analyzed the potentiality of involving local administrations and professional tourism operators to create new tourist itineraries by valorizing existing hiking trails. Firstly, the Municipal Structural Plan should include an archaeological survey; secondly, local tourism stakeholders will benefit from a destination management action to promote environmental and socio-cultural sustainability.

Definitely, *community-involved tourism* may represent the balanced intersection between community and development through policymakers' actions and decision-making [57]. In this view, the socio-political framework of tourism, involving governance measures, has to include environmental requalifying and destination planning [56].

Policy measures for sustainable and resilient tourism should focus on culture-led and community empowerment activities, such as preserving the history and memory of the place, promoting slow tourism and cultural innovation, as well as implementing digitalization activities.

3.2.4. Sites and trail's state of art **??**

This section defines the points of interest selected to position the QR tags, and reports on their accessibility and state of conservation. This may be relevant in a perspective to spot the segment of users that may take advantage of the tag.

The cave named *Buca La Piella* is the foremost site from an archaeological point of view. It is located in a fascinating environment outside conventional circuits, which is why it is less frequented and consequently less compromised. It is reachable leaving a marked path to follow the bed of a tributary of the *Lima* stream. The trail is dotted with minor karst caves, and the *Buca La Piella* is reachable by climbing up on a steep slope in the wood on the left of the watercourse.

Not far from the *Buca La Piella* on the same side of the river is another karst cave named *Antro dell'Ugola*. It is reachable following a faint and intermittent track that departs from a marked path. It is characterized by a suspended geological formation reminding an uvula, hence the name.

Both caves are going to be analyzed in the course of the Underlandscape project [81,82], and findings can further enhance the interest in both sites.

Along the dirt road from the village in the direction of the lake of *Casoli* are some of the most interesting sites. The medieval remains of the church of *Sant'Andrea de Lacu*, now in a state of serious disrepair, without its roof and with static problems, but characterized by its Romanesque forms and 10th-century decorations.

The *metati* (structures for drying chestnuts), together with the hundred-year-old chestnut trees, testify to the exploitation of forest resources since the Middle Ages.

A little further along the CAI path is the oratory named *Madonna di Col di Piano*. Recently renovated, with its canopy it has been a shelter for wayfarers since modern times.

Inside the town of *Casoli*, narrow streets branch off to the main square, where the medieval church dedicated to the Saints *Donato* and *Andrea* with its bell tower can be admired. From here, an ancient street climbs to the top of the hill. On the way up there is a small oratory called *Madonna di Castello*, still consecrated but in poor conditions.

On the summit are the remains of the medieval castle with its walls. In need of consolidation of the walls, it cannot be visited at the moment as it is on private property; it is only possible to observe part of its structures from the path.

Two other sites that are particularly curious but cannot be visited because located on private properties are the so-called *Celtic Calendar*, an artificially excavated rock interpreted as a kind of sundial, and an epigraph reused in a house interpreted as Lombard.

3.3. Implementing a QR-based signage

The concept behind the implementation of the QR-based signage is to guide the visitor through a self-organized experience. To verify on the field the practical aspects and deployment we realized and placed several QR tags. The list is in Table 2.

The proposed signage cannot replace CAI one (see figure 1a), which is recognized throughout the country and is very effective. The QR-based signage complements it and provides more detailed information at multiple levels. For one, the availability of written directions along the trail leading to the *Buca La Piella*, which is hard to follow and not covered by CAI signage, is of great help to inexperienced hikers.

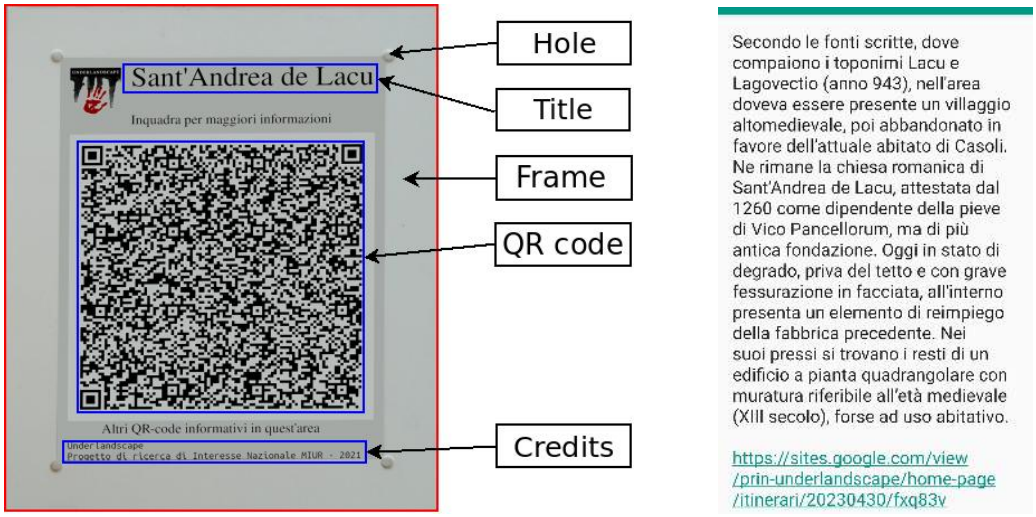
Tags are printed on Synaps™, a non-biodegradable polyester synthetic film by Agfa-Gevaert NV. Agfa documents the production process giving guarantees of sustainability [78]. According to Agfa, Synaps is more sustainable than laminated paper. From previous experiences, it is also more durable.

To minimize the environmental footprint, the tags are attached to pre-existing structures, like trees or poles. The tag is tied with a thin biodegradable string, as in figure 7a.

The QR tag is designed to implement three levels of reading (LoR), with an increasing level of technology involved:

- visual: the information is printed on the tag. The user does not need any technology to read the content;
- QR tag text: this is the text encoded in the tag. The user needs a smartphone-like device and an appropriate app to read aloud or translate the content;
- URL: these are Web URLs encoded in the tag text. The user needs an Internet connection to visit the URL.

We placed QR tags both along the trail and at sites of interest; the former are at detours or at close range so that from one you can see the next, as per the CAI standard [58]. They can therefore have the function of a simple signpost to visually indicate the continuity of the trail. The second LoR gives access to the written indications recorded within it, which are more accurate and precise than those printed on the tag. The third LoR provides further capabilities, as detailed below, but is accessible only whenever the location is covered by the Internet.



(a) QR-tag parts

(b) QR-tag content on a 5.5′ screen

Figure 5. QR tag parts and content

There are many ways to distribute the content among the three LoRs, dictated by tag purpose and location. For our experiment, we used the same organization for all tags, which privileges the second LoR, namely the text encoded in the tag (see figure 5a):

- visual LoR (see figure 5a): the tag is approximately the size of a game card, 80 cm^2. 40% of the frame (32 cm^2) provides mechanic resistance to the holes needed to secure the tag. 60% of the remaining (48 cm^2) contains the QR-code, 20% for a heading containing the name of the location, one line instruction for use, and the project logo, and a footer (12%) for further instructions and project credits;
- QR text LoR (see figure 5b): it describes the site or gives directions to reach the destination of the trail. The text includes historical, archaeological, and naturalistic information, together with the URL for the next LoR. In our prototype, the maximum length of the text amounts to 700 characters. A Huawei FIG-LX1 (2017) decodes the tag from a distance of more than 50cm using an Android application available on the Play Store. The same phone can read aloud the content (in Italian) without Internet connectivity;
- URL LoR: such information is useful only in a few locations since the area is not uniformly covered by broadband networks: for instance, during a recon to the *Piella* cave, none of the smartphones of the participants received sufficient broadband network signal to visit the linked page. However, the application records the URL so that the user can visit it when entering a covered area. Each Web page contains site-specific information, an interactive map hosted by the uMap web service (https://umap.openstreetmap.fr/it/) with the location and content of all the QR tags (see the left box of figure **??**), and a form for user feedback.

The production process of a series of tags has also been investigated to streamline the task and use only basic Information Technology skills.

The master document is a *GeoJSON* file describing the area and the tagged features: a GPS tracking application can be used to record an initial version of it during a recon.

The finalized master document contains a single *GeoJSON FeatureCollection* object containing one *Feature* object for each tag. Each *Feature* contains a *Geometry* object of type *Point*, and a *properties* object with fields containing information needed to create the tag: its unique identifier *uid*, a random string of six lowercase letters used to produce the associated URL, the *title* printed on the tag, and the text to be encoded in the QR code (see figure 3)

The *properties* are also shown on the UMap map.

Name	Long	Lat	FID	Length
Buca La Piella	10.68361	44.03667	t5ysrm	476
Calendario celtico	10.66985	44.03986	my0kp8	484
Castello	10.67062	44.04004	4l4r6y	597
Chiesa dei SS. Donato e Andrea	10.66947	44.03928	lwtyx6	632
Iscrizione longobarda	10.67244	44.03906	60m75s	369
Lago di Casoli	10.67761	44.03468	xqjpbk	369
Madonna di Castello	10.66994	44.03960	qlci89	395
Madonna di Col di Piano	10.67760	44.03173	3w44wr	414
Metato	10.67764	44.03591	sbgnl0	660
Sant'Andrea de Lacu	10.67592	44.03530	fxq83v	657
Antro dell'Ugola	10.68296	44.03871	mprs0w	226
Deviazione per Antro dell'Ugola	10.68343	44.03971	e4n2js	88
Deviazione per Buca La Piella	10.68427	44.03573	hve4pj	139
Deviazione per Sant'Andrea de Lacu	10.67663	44.03507	13uav3	200
Ingresso Buca La Piella	10.68358	44.03592	5ahvp8	190
Riparo sottoroccia lungo percorso Piella	10.68401	44.03573	kwr1wx	286

Table 2. The QR-tags placed around *Casoli* . The FID (Feature IDentifier) is a random code that appears on the web page linked to the QR code. The Length refers to the description in the QR tag and is in characters.

```
{
  "type": "Feature",
  "geometry": {
    "type": "Point",
    "coordinates": [10.67592,44.035298]
  },
  "properties": {
    "fid": "fxq83v",
    "name": "Sant'Andrea de Lacu",
    "description": "Secondo le ... ad uso abitativo.",
    "imageTag": "1m0Vad1Om2ihSVezPUkMKfuCUlg3ptC6z",
    "urlPrefix": "https://sites.google.com/ ..."
  }
}
```

Table 3. *GeoJSON Object* of a feature associated with a QR-code. Ellipsis (...) are used to shorten long strings

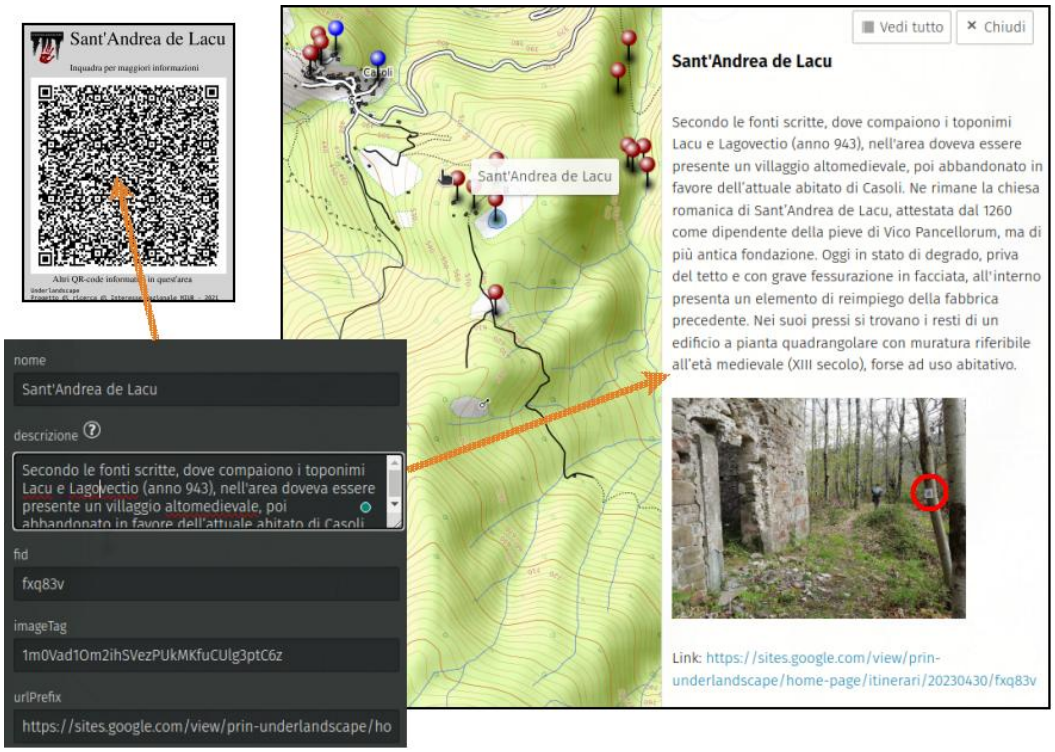


Figure 6. Generation of the QR tag and UMap visualization from UMap content. The uMap editor (bottom left) provides a simplified access to the GeoJSON description. The same interface allows to specify the template controlling the Web visualization of the map (right side). An ad-hoc application referenced in the paper allows to transform the uMap file downloaded from the server into a batch of printable QR tags (top left). The tag is highlighted in red in the picture on the Web display

Editing the map downloaded from the GPS app to fill in the *properties* does not require technical skills, since the tools integrated into the UMap user interface already fit the purpose (see figure **??**). The resulting *GeoJSON* object describing a tagged feature is shown in figure 3.

The master document is rendered by UMap on the page linked to the tags (as in figure **??**).

A *Bash* script running on a Linux system makes straightforward the conversion of the *GeoJSON* file into a printable array of QR tags. The code, a total of 90 source lines written in Bash and Python makes use of the `ogr2ogr` and `qrencode` commands, and is on GitHub [80].

4. Results and discussion

We aim to enhance the tourist experience in an inland area located around the village of Casoli. Our goal is tightly related with the fourth pillar of sustainability: there are natural and cultural assets that need to be nurtured or at least preserved. We concentrate on a signage system, the realization of which is finalized to reaching such cultural result.

To avoid the over-tourism pitfall, we need to take into account the other three pillars: social, environmental, and economic. To this end we analyze the social fabric that will host our initiative, the environment where signage will be deployed, and the economic framework that will support its implementation. From this study we derive the requirements for our signage system: low environmental impact, open to participation of the residents, easy to use from the visitors, and economically sustainable with a minimal touristic flow.

The approach we applied to reach such conclusions is summarized below: it is conceptual and therefore applicable to a wide range of use cases, and merely consists in designing the system with sustainability in mind from the early stages.

(a) A tag secured to a tree near a shelter

(b) Google Earth view of the surroundings of the tag. The map is north-oriented, and shows the village of *Casoli* in the left-high corner

Figure 7. Tag placement at different scales

Our design started by defining a profile for the area according to the *three pillars*. The environmental aspect is characterized by natural formations and human artifacts tracing back to the Paleolithic Era. As for tourism-related economics, a qualitative and quantitative analysis [49] reveals unique features that need to be capitalized on to enhance the tourism potential. Given the touristic trends and the local vocation, we conclude that Casoli is a small destination for visitors practicing heterogeneous touristic circuits in individual and combined ways. Cultural sustainability mandates the involvement of local stakeholders in planning new heritage itineraries and supporting initiatives, including signage.

An outcome of the analysis of the social fabric is that, in order to preserve the native social and economic framework, mass tourism is not a candidate target, while a motivated, non-casual visitor is preferable. Regarding the potential reasons for a visit, we found a cave inhabited since pre-history but reachable with some effort, a village with historical buildings, and nearby architecture dating back to the Middle Ages. Such targets offer a variety of access ways, from those requiring performance to the relaxing ones. For this reason we opted for not suggesting a geo-itineray, allowing the user to follow personal inclinations. In this way we expect, justified by the results of [23], that the educational impact of the signage is maximized.

We investigated a technique for guiding the visitor and telling the history of the place. The small number of expected visitors limits financial investment, while the natural heritage requires non-intrusive techniques.

The proposed solution consists of placing at selected locations the QR tags listed in table 2. The total cost of the tags amounts to a few Euros for the printing service, although finding a shop with an appropriate device may be difficult. The impact on the environment is extremely limited, as shown in figure 7.

Previous investigations, including archaeological surveys and access to historical documents and cartography, allowed to design the contents to be delivered through signage. Two on-site surveys provided further practical indications and the opportunity to place the QR tags.

The main result from our activity is the real scale deployment of the signage, a non trivial exercise in holistic sustainable design.

As a side result we have a signage technology based on QR code tags, a benchmark difficult to improve in terms of environmental impact and cost.

Collecting statistics about user perception is not a primary interest for us at this stage: the initiative started as an exercise and was not adequately advertised to the potential users. However, we provided two ways to collect data as part of the exercise.

One is a poll in five points on the web pages linked to each tag. The user is asked to quantify an agreement (0-do not agree, 5-strongly agree) with four sentences, and finally provide an answer:

- the QR tag was useful
- a plaque would be preferable

- I will come back to visit the sites I did not visit today
- I am satisfied about my visit
- I scanned other QR codes in the vicinity

The other is an hits count on the pages linked to the QR-codes.

Both of them proved to be ineffective. We collected only one form with a positive feedback but with no statistical significance. The hit count was polluted by spurious accesses to the page (for instance for maintenance, or reaching the page from the map) and by the fact that scanning the tag was not necessarily linked to a hit.

The reactions we collected by interviewing local stakeholders are positive, which gives us the impression that the initiative is respectful and consistent with the social and economic framework. The measurement of the efficacy in financial terms is currently beyond the scope of this paper and will be assessable only in the long term depending on the collaboration of the involved stakeholders.

Although we are satisfied that the solution complies with the sustainability principles that inspired this work, we identified two issues that indicate directions for future research:

- The balance between visual impact and effectiveness is critical. The current dimension of the tag is such that the visual impact is limited, but this negatively affects its efficacy: it is easy to miss a tag containing possibly relevant information;
- Monitoring visitor's activity, like the frequency of visits of a given tag, or the sequencing of visited tags, which may be of interest for managing the site, is currently ineffective.

Trading off cost and simplicity for effectiveness and measurability there are alternative solutions.

One technology that fits the requirements of our task is Bluetooth Low Energy (BLE): the autonomy of a battery-operated BLE device is compatible with the periodic maintenance of other forms of signage. A Bluetooth device can send to the visitor's smartphone a beacon to indicate the presence of a passive sign, like a not-so-visible QR tag, or directly deliver information. However this requires the installation of the app on the visitor, and the design of the IT product including the device and the application, which may cost far more than the physical devices.

A different application-based solution privileging passive devices is based on a writable NFC tag close to the one delivering the content. To update the number of visitors that have read the informational NFC, the user application reads and increments the count recorded on the writable NFC. Here too the primary drawback compared with our QR-tag based solution is the need for an ad-hoc application. In addition, the event of data pollution is not excluded.

The demonstration of the existence of such needs biases the technological evolution: for instance, if counting NFC reads were a frequent requirement, tags with such a feature would be produced at low costs, and the increment operation might become a default in NFC reading apps. The research on low-energy and low-cost devices is also that of demonstrating that the market for such devices is expanding.

5. Conclusions

Tourism, like other productive activities, is at risk of being unsustainable and damaging the very resources that support it. To avoid heavy drawbacks the design of a tourism initiative has to consider the complex framework where it will operate according to an *holistic* approach. A methodology made of examples and guidelines helps cope with such a challenging task.

This paper is a step in this direction. We address an ordinary problem, that of providing the visitor with directions, with the aim of promoting slow tourism and preserving distinguishing traits of an inland area.

We show how a balanced use of technology may help in the task, with a process that is necessarily multidisciplinary, joining skills coming from the diverse domains: sociology,

economics, humanities, and engineering. The paper demonstrates how their interplay returns ad-hoc tools targeting sustainability and efficacy.

The resulting implementation is minimalistic in its deployment. The detailed description enables its reuse as a starting point in future initiatives.

On the technical side, the discussion regarding the deployed experiment indicates directions for future investigation. The definition of a potential application will foster research aiming at passive or very low-energy devices that can effectively advertise their presence and collect statistics.

From a different point of view, the lack of discoverability suggests a recreational scenario inspired by Geocaching® and Pokemon-GO®.

In conclusion, more sustainable solutions to old problems exist and are reachable melting technology and humanities. Policy-makers are crucial in the development and monitoring of sustainable measures. This is especially important in the tourism industry where sustainability is a multifactor topic that includes resident ecosystem resilience and regeneration efforts by both policy-makers and private tour operators.

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Abbreviations

The following abbreviations are used in this manuscript:

URL	Uniform Resource Locator
QR	Quick Response
GeoJSON	Geographical JavaScript Object Notation
CAI	Club Alpino Italiano
UNESCO	United Nations Educational, Scientific and Cultural Organization
SCC	Single Chip Computer
NFC	Near Field Communication
EEC	European Economic Community
SCI	Sites of Community Interest
SAC	Special Areas of Conservation
SPA	Special Protection Area
ISTAT	Istituto Nazionale di Statistica

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