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A resources ecosystem for digital and heritage-led holistic knowledge in rural regeneration

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ABSTRACT

This paper presents a digital resources ecosystem prototype of integrated tools and resources to support heritage-led regeneration of rural regions, thanks to a deeper understanding of the complexity of cultural natural landscapes throughout their historical and current development. The ecosystem is conceived as a distributed software platform establishing data ecosystem and open standards for the management of information, aimed at providing different services and applications to address the needs of the various end-users identified. The platform has been conceived and realised in the framework of a Horizon 2020 research project, with a view to building a set of holistic knowledge about rural regions and their cultural and natural heritage and making it available for long-lasting heritage-led territorial processes of change. It is the product of a multidisciplinary collaboration amongst heritage, digital humanities and ICTs experts, and combines data and methodologies from a range of approaches to humanities together with the customisation of effective digital tools. It has been designed for deployment also in cloud systems compliant with the Infrastructure-as-a-Service paradigm. All data is Findable, Accessible, Interoperable, Reusable (FAIR data). It hosts and integrates different tools, making the data gathered with/for local stakeholders usable and making the same data re-usable within the tools' functions, generating integrated heritage knowledge. It comprises data on 19 rural pilot territories, where the tools and their integration have been developed and tested, while 62 more are partially included as additional territories which participate in certain activities within the project. The main testers for this platform and its functions are the local stakeholders of these territories. The paper describes and analyses the platform and its impact, discussing the integration of tools as an innovative approach that goes beyond the use of individual tools in shaping a multidimensional vision. It also offers an analysis of the potential of an integrated digital ecosystem in evidence-based and place-based regeneration strategies. Some reflections for developments and cooperation during the pandemic are also presented.

1. Introduction

In recent years, Information and Communication Technologies (ICT) and computational methods in humanities have been providing important supports to enhance cultural heritage [1]. Digital tools and methodologies can improve heritage knowledge-building, cultural understandings and data sharing; they can allow people to interact with heritage and engage actively in territorial development; they can support the use of knowledge to improve governance and management functions [2]. This purpose is so significant that it motivated the launch of a public consultation for developing a European digital platform on cultural heritage [3,4].

Computational approach and visual systems have shown their effectiveness in improving the understanding of heritage and sys-

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tems of interpretation and communication of key factors for territorial developments [5,6]. However, systems of descriptions and interpretations have been conceived for a variety of purposes such as addressing cultural or economic values [7–10].

Computational models are suitable for studying complex systems [11], such as cultural natural heritage-based regeneration processes in rural areas [12], where there are no intuitive analytical solutions. In Barrientos, et al. [13], a systematic literature review shows the correlation between the class of computational method and its scope and area of application with regard to rural areas, and proposes some alternative uses in fields where there is less evidence of their applicability. In Tamborrino, et al. [14] a comparative analysis of some digital platforms in the field of heritage is developed by considering the project aims, the platform aims, the tools hosted by the ecosystem and the data. As a conclusion it is observed that heritage tools are mostly conceived and offered as separate modalities and are not included in a digital environment conceived as a whole for fully integrated functionalities and methodologies. Moreover, end users are not part of the design and implementation process.

Beyond this divide, the RURITAGE Resource Ecosystem (RRE, available at https://www.ruritage-ecosystem.eu) is developed as the digital shared environment to enable a digital and heritage-led methodology for fostering a novel vision in the development of rural territories. It aims to support the way local knowledge is used and built in a framework that is aware of good practices and experiences at global level.

The digital ecosystem has been conceived and realised within the framework of the Horizon 2020 research project RURITAGE (Rural regeneration through systemic heritage-led strategies, https://www.ruritage.eu) which is a large multi-partner global EU funded project aimed at developing and experiencing a heritage-led strategy based on the identification of systemic innovation areas (including art and festival, integrated landscapes, local food, pilgrimage, migration, and resilience) and extraction of knowledge from "role models" that are already tested, to be transferred to "replicators" and other rural areas [15]. A complete list of role models and replicators is included on the website of the project. For these purposes, RRE has been conceived as a digital open platform that hosts several tools for supporting cultural natural heritage (CNH), territories and public engagement, and namely:

- the Web Geographic Information System (GIS)-based ***Atlas***
- the ***Monitoring Platform***
- the ***My Cult-Rural Kit***
- the ***Digital Rural Heritage Hub*** (DRHH)
- the ***Decision Support System*** (DSS)
- the ***Replication Toolbox***

RRE provides a shared digital environment for the storage, development and dissemination of knowledge generated by surveying territories with their physical and historical features and actioning heritage-led strategies for the regeneration of rural regions. It is a tool that combines and integrates a range of different functions, addressing effective ways to characterise and observe existing resources in rural territories from the past to the current CNH (using an atlas), to exchange good practices (with methodologies to mentor in a digital hub) and to monitor the effectiveness of heritage-led regeneration strategies built upon local heritage (using monitoring systems, including mobile apps for co-monitoring). It is worth noting that, as elaborated below, RRE is flexible and can accommodate further extensions to be implemented by tools developers for other territories under request of other interested stakeholders; so new tools (e.g., new Apps, new analytics, etc.) and further use case analyses can be designed and developed to suit new user needs and requirements. Lastly, RRE is opened integrating third-party software.

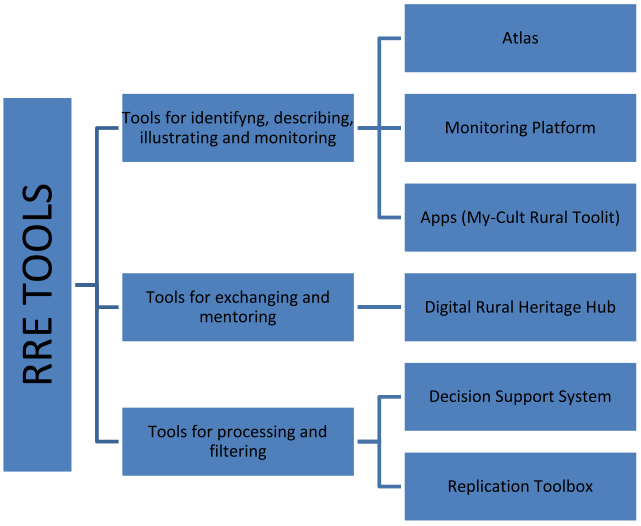

Fig. 1. Illustration of the aims of RRE (Ruritage Resources Ecosystem) tools.

RRE has been conceived and designed to be a distributed software infrastructure that follows the Service orientated Architecture software design pattern and as further explained below, this allows the development of distributed software components that cooperate together, creating and establishing a strong integration of digital tools for heritage-led initiatives. With this aim and following the FAIR (Findable, Accessible, Interoperable, Reusable) data approach [16,17], RRE shapes a shared digital environment that integrates, correlates and provides heterogeneous information (e.g.: cultural, socio-economic, demographic, behavioural and environmental) gathered and developed on different scales and with different granularity. As an open platform RRE is available at https://www.ruritage-ecosystem.eu which provides an entry for interested parties to get involved and/or get further information.

Data from several tangible and intangible CNH sources as well as different socio-economic analyses and threats are included for 19 rural territories (principle "role models" and "replicators") [18], although 62 more rural territories are partially included during the project runtime, reaching a total of 81 rural territories [19]. RRE also integrates third party software and datasets, such as CORINE land cover data [20], and demographic data from EUROSTAT [21].

As illustrated in Fig. 1, RRE tools support these local stakeholders in different ways.

2. Research aim

RRE aims to answer to the need of a holistic and structured knowledge about CNH as a resource (firstly considered for its cultural and historical values) within the context of territories and to empower stakeholders of rural areas with state-of-the art digital tools. For this purpose, it provides multifaceted information and user-friendly access. Information is shaped using different approaches to humanities (e.g.: planning, historical, economic, communication), which gather and organise heterogeneous data with different goals and for different end users, but with the same methodology in making data FAIR [16]. RRE provides an integrative spatial approach, performance measurement, interactive visualisation, decision support systems and interoperability with other data infrastructures [22].

- The purpose of the research is to make existing scattered heterogeneous data available, organising and finalising it, to allow teaching/learning procedures, providing step by step method-

ologies not only for shaping a multidimensional vision but also for actively undertaking the regeneration of rural regions.
- Within this research framework, RRE architecture's main aim is designing and realizing a novel, integrated and user-friendly digital platform for an evidence-based holistic and dynamic knowledge-building and sharing of CNH within territories through tool integration.
- The specific objective is to foster and facilitate actions across a variety of tools. With this aim, RRE enables the exchange and re-use of data and information by re-directing the same data gathered and organised into various datasets by different research partners to specific tasks, thanks to the integration of tools and datasets.

3. Materials and methods

Research has highlighted the vital role of rural areas in building resilience [23,24]. One of the most recent instances of this role has been the pandemic experience, which speeded up digital transformation and technologies also in these areas [25]. To leverage this potential and create a truly impactful platform focused on CNH-led rural regeneration, RRE tools were developed.

3.1. Digital platform of holistic heritage knowledge for heritage-led regeneration

RRE is a distributed software platform establishing data ecosystem and open standards for information management aimed at providing different services and applications for reframing CNH as a resource of territories to take evidence-based strategic actions and implementing RURITAGE methodologies to answer the needs of the various end-users identified. One of its main purposes consists of exploiting data and making it available following the FAIR principles [16].

For this purpose, RRE has been designed and developed following the Service orientated Architecture (SOA) design pattern, [26] allowing the development of a highly distributed software in which each component exploits the Internet to enable the data exchange. From this point of view, a Service is a discrete unit of functionality or a set of software functionalities that can be accessed remotely and acted upon and updated independently. Different software entities can reuse the Service for different purposes. A Service can exchange information with other Services through communication interfaces over the Internet. The resulting RRE software infrastructure addresses the following main requirements:

- *Interoperability* amongst heterogeneous systems and technologies;
- *Scalability,* to handle a large number of users and a large volume of information stored, exchanged and processed;
- *Reliability*, to avoid or prevent possible failures and overloads;
- *Evolution over the time*, supporting rapid modification and enhancement with low cost and reduced architectural impacts;
- *Modularity,* designing the system as a collection of interoperable components that communicate through lightweight mechanisms;
- *Extendibility,* to be capable of adding new functionalities and supporting software updates, the correction of bugs, security policies and permission updates;
- *Decentralization,* to ensure that each service is able to implement its functionalities using the most appropriate technology. Consequently, the software components perform independently;
- *Flexibility*, supporting heterogeneous services with different characteristics and requirements;
- *Standardization,* to foster data exchange by exploiting common interfaces and open data-formats;
- *Security,* to guarantee authentication, data access, confidentially and privacy.

As shown in Fig. 2, RRE consists of three-layered architecture with i) a *Data-source Layer*, ii) a *Distributed Core Components Layer* and iii) an *End-users Applications Layer*.

The *Data-source Layer* collects all the heterogeneous information that has been identified and analysed including audio/images, maps, shapefiles and alpha numerical documents. It is worth noting that all the data stored and managed in RRE is compliant with the European General Data Protection Regulation (GDPR) [27]. Furthermore, the *Data sources Layer* also integrates third-party platforms, such as Copernicus Land Monitoring Service (CORINE) Land Cover [20] and Natura 2000 [28]. CORINE Land Cover is part of the Pan-European component, while Natura 2000 is part of the local component of Copernicus and both are coordinated by the European Environment Agency. The RRE data is autonomously retrieved by the respective software platforms.

The *Distributed Core Components Layer* provides developers with a set of Services designed using the SOA approach by exploiting REST Web Services [29] to develop a distributed software infrastructure that can be deployed on different servers and cloud systems. REST stands for Representational State Transfer, guiding both design and development of distributed Services that exploit the widely used HTTP (Hypertext Transfer Protocol) for data exchange over the World Wide Web (www). Consequently, the various Services (i.e.: software components in Fig. 2) can interoperate by sharing and autonomously exchanging information over the Internet, establishing Machine-to-Machine communications. Each individual Service provides endpoints in the form of URLs (Unique Resource Locators) returning information following JSON and GeoJSON, which have been chosen as the main data-formats for data exchange amongst the different Services and applications in the whole RRE. JSON stands for JavaScript Object Notation. It is an open and standard data format for storing and transmitting information as human/machine-readable text. GeoJSON is a variant of JSON which reports non-spatial information with geographical features (e.g.: georeferenced points, line strings, polygons and multipart collections of these types). This layer aims to (i) allow interoperability across heterogeneous technologies, (ii) store all the data and make it available in the Data Source Layer, (iii) post-process, correlate and analyse the heterogeneous data and (iv) provide remote services to develop distributed applications and tools.

We developed different autonomous services to expose the heterogeneous data, forming the *Distributed Data Storages* shown in Fig. 2. In its core, each data storage Service implements a MongoDB database (https://www.mongodb.com/). MongoDB is a non-relational, document-orientated database management system. It moves away from the traditional table-based structure of relational databases in favour of JSON-style documents with dynamic schema. This makes the integration and management of heterogeneous information more flexible. For further extensions, new services can be developed thanks to the SOA approach adopted to develop RRE, implementing other database management systems that can better address requirements to store new information needed by future applications and tools without reimplementing the whole RRE from the scratch. This data, stored in MongoDB and made available by REST Web Services, is mainly gathered from static datasets or uploaded by end-users via RRE tools, such as My Cult-Rural Kit and DRHH.

The End-users Applications Layer represents the highest layer of the infrastructure proposed. It consists of a set of applications for end-users. At this level, interoperability is enabled between low-level heterogeneous technologies. Thanks to the software interop-

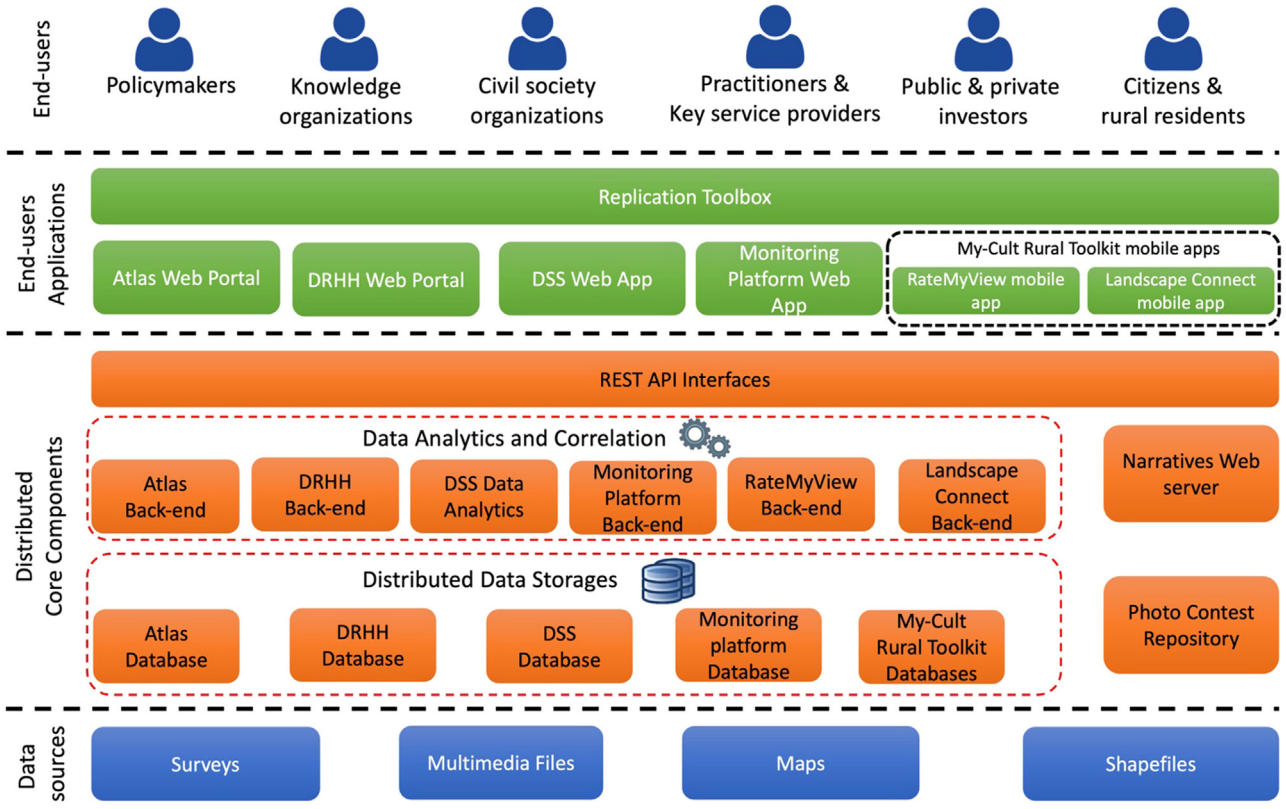

Fig. 2. Schema of the RRE distributed software platform (DRHH: Digital Rural Heritage Hub, DSS: Decision Support System).

erability amongst the different services (i.e.: the blocks shown in Fig. 2), different tools have been integrated with their different functionalities.

It is worth noting that the whole RRE has been developed in consideration of possible future extensions, which could also include the development of new digital tools and interoperability with third-party software. More database management systems can be integrated in RRE without refactoring or redesigning the whole RRE and the system has been conceived for storing different and heterogeneous data, according to the availability of information that can change territory by territory (size depending only on the quantity of data available in the territories according to the structure presented in Fig. 2). Examples of possible future extensions are new Apps and/or new software analytics coming from further case analyses and implemented by tool developers. These software extensions coming from new case analyses can provide new requirements and requests from other territories and interested stakeholders.

The FAIR data approach and tool integration allow the reuse of data to address different functionalities and purposes. The combination of the different data sets allows the triangulation of data between stakeholder input, performance data and existing datasets relating to the area. This provides a rich source of data for planning, development and conservation. Fig. 3 shows the datasets and the workflow.

3.2. Identifying, describing, illustrating and monitoring CNH

A heritage-led regeneration of rural territories requires the identification and description of CNH in territories [30]. A far-reaching approach is needed when it comes to analysing and visualising features and factors, to include several kinds of tangible and intangible heritage categories and innovative actions, more specifically, to enable an understanding of the rural landscape as a whole. It should consider landscapes as the cultural natural environments that are identified by human-territory interactions expressed in living territories under continuous change [31,32].

To achieve these goals, we developed the Atlas. Atlas is an interactive environment that allows guided and structured engagement with the data which has been constructed collectively with local stakeholders via a dynamic bottom-up approach [33]. By adapting an updated vision for rural areas [34], a digital instrument has been provided to support rural prosperity and rural proofing [35]. Fig. 4 shows the main Services distributed by RRE which cooperate together to make up the Atlas. The Atlas web portal (green module in Fig. 4) is a web application through which end-users can access information.

An integrated assessment procedure is also needed to measure the performance and impacts achieved through the implementation of heritage-led regeneration plans. In RRE, this goal is achieved by hosting a Monitoring platform that provides quantifiable evidence of the role of CNH in rural areas as a driver for sustainable growth. This platform is based on Key Performance Indicators (KPIs) based on capitals (cultural, natural, built, social, human, financial) and has been implemented in the six rural areas around Europe that act as *replicators*. It has been developed as an online interactive dashboard tool which provides helpful insights based on KPI charts and diagrams. It works by analysing the performance of the action plans deployed in rural areas through selected cross-thematic and multiscale KPIs and through the implementation of a holistic approach based on system dynamics for properly assessing heritage-led regeneration.

The KPIs identified are related to the six capitals considered in the Community Capitals Framework [15]. More than 200 indicators were identified and assessed, and 60 were actually selected.

A Global Performance Index (GPI) has been defined [36,37]. This index combines all the values of the indicators in a single value.

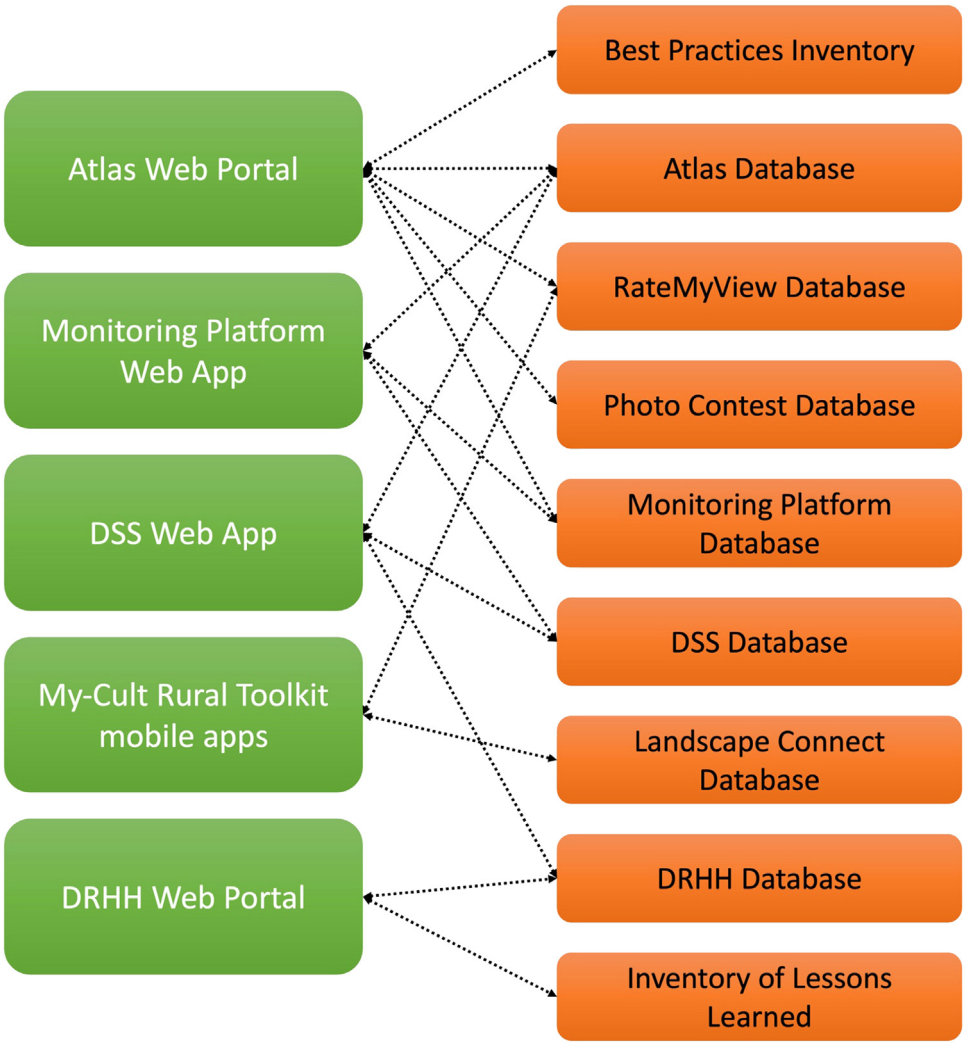

Fig. 3. Datasets and workflow of the RRE tools (DSS: decision support system, DRHH: digital rural heritage hub).

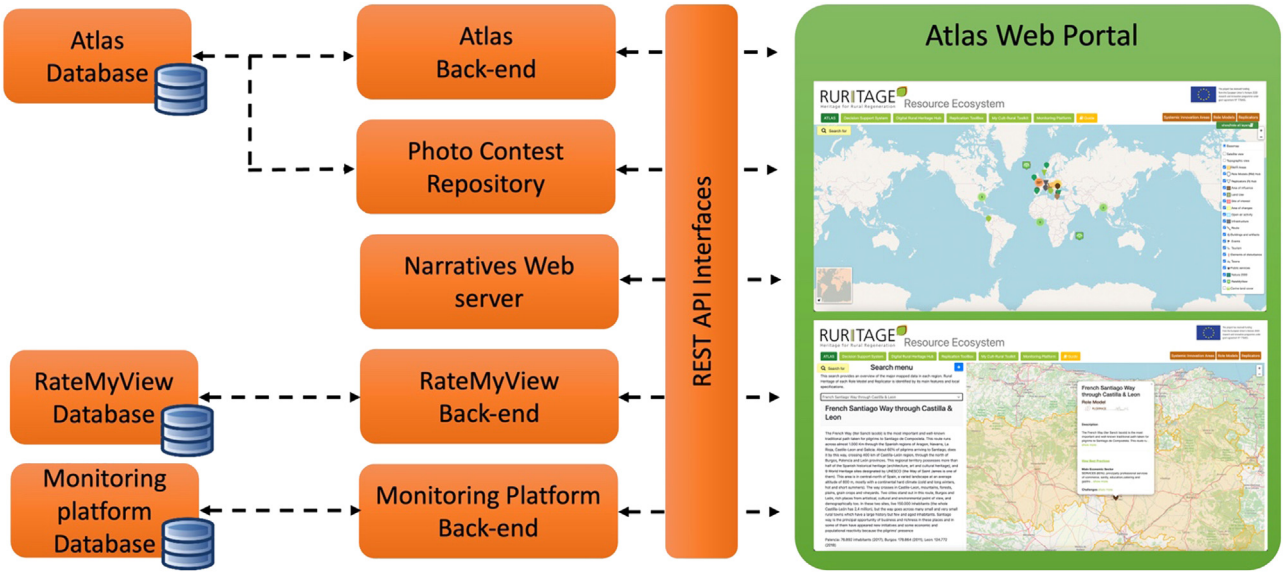

Fig. 4. RRE Services in the ATLAS and their communication flows.

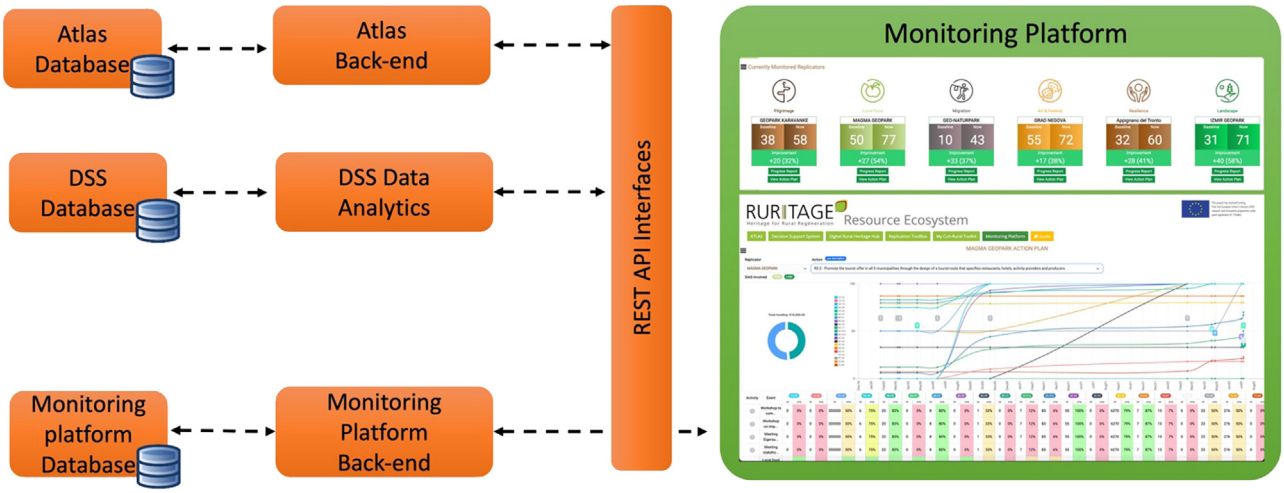

Fig. 5. RRE Services in the Monitoring Platform and their communication flows (DSS: Decision Support System).

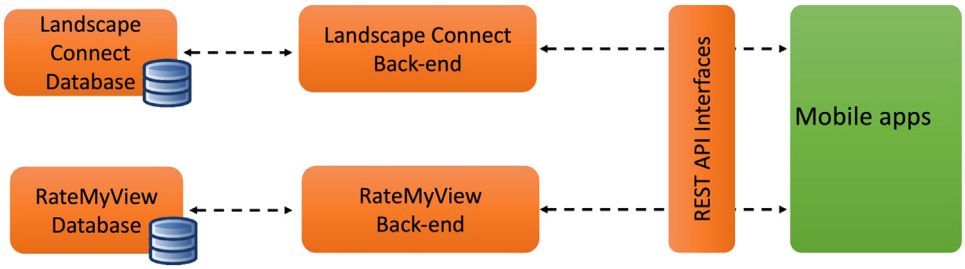

Fig. 6. RRE Services in the My-Cult Rural Toolkit and their communication flows.

When calculating the capital values and the GPI for each rural area, not every KPI has the same impact. The way to obtain the weight of a KPI is through Group Decision Making (GDM), collecting, analysing and combining opinions from domain experts through the Analytic Hierarchy Process [38] and Ordered Weighted Averaging [39]

While providing its own web application, the Monitoring platform has been integrated with the Atlas for the visualisation of KPIs for each territory [Fig. 5].

RRE also includes co-monitoring methods by hosting the My Cult-Rural toolkit. Martin et al. [40] describe how it combines community workshops with ubiquitous mobile phone technologies to extend the reach of the engagement. These two approaches to data gathering comprise (i) Physical tools based on three participatory workshop methodologies: Mini-Landscapes, Object Mapping and Walking Maps, and (ii) Digital tools that use two participatory mapping methods facilitated by mobile phone (tablet) apps: Rate my View and Landscape Connect. Free mobile phone applications (apps) are available for the two major mobile platforms. The apps are free to download and they allow the collection and georeferencing of text and images, using smartphones or tablets. Both apps allow in-the-field user data collection, combined with a server-based *back-end* that allows real-time data analysis by researchers and workshop facilitators [Fig. 6].

The images and text collected by Rate my View are uploaded as JSON documents with the picture taken by the end-user to the Rate my View database, exploiting the REST Web Services provided by Rate my View *back-end*. The REST Web Services are also used by the Atlas to retrieve information from Rate my View.

The Landscape Connect Mobile App exploits the REST Web Services provided by Landscape Connect *back-end* to download and upload questionnaires and responses stored in the Landscape Connect database. JSON is the data format chosen to manage information within the questionnaires.

3.3. Exchanging and mentoring

For exchanges and mentorship, the DRHH is created on the RRE software platform. DRHH aims to be a forum for discussion amongst local stakeholders to allow knowledge sharing related to the areas of systemic innovation. Target users comprise members of the RURITAGE community playing as Role models and Replicators and their respective stakeholders (both internal and external to the RURITAGE project) and other core RURITAGE members as facilitators. The forum included knowledge exchanges amongst the RURITAGE *role models* and *replicators* and a digital hub hosting internal discussion of each hub. Currently, 382 users and over 40 discussion groups/digital hubs are active on the DRHH. RRE provides open access to explore the DRHH exchanges while registration allows only engaged stakeholders to directly interact by logging in. The different coordinators of the local hubs and their stakeholders can access the forum with a moderator of discussions, to share and exchange ideas on possible actions to be implemented during the co-development phase of the heritage-led regeneration plans. Moreover, the DRHH also includes educational and capacity-building activities through a series of webinars on the topic of each systemic innovation area.

The DRHH has been created using the open-source application NodeBB (https://github.com/NodeBB/NodeBB). It is a modern discussion platform that also provides features for instant interaction and real-time notification. Starting from the bare minimum installation, we customized Graphical User Interface to satisfy the requirements. The NodeBB functionalities have been extended by developing new REST Web Services to fully integrate the DRHH into

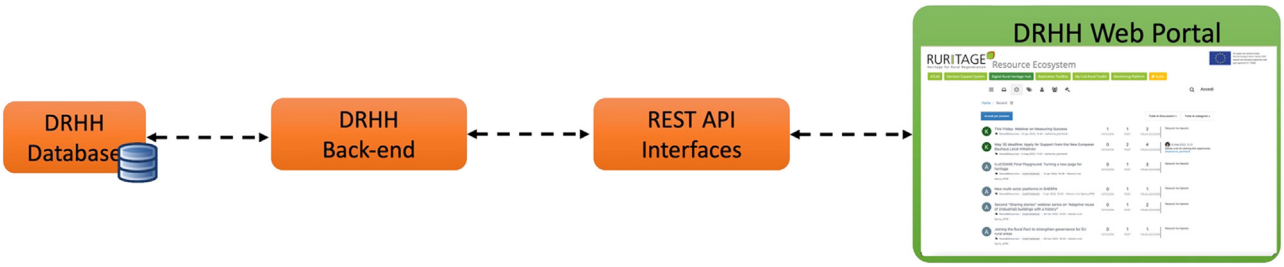

Fig. 7. DRHH (digital rural heritage hub) services and communication flow.

the whole RRE. Consequently, the raw and post-processed information can be easily shared with other Services and tools over the Web. Fig. 7 shows the DRHH software schema.

In addition, users can create their posts using a simple text box with features to attach multimedia files.

The DRHH *back-end* shown in Fig. 7 integrates MongoDB as database management system, as the information to be stored does not have a predefined data structure. DRHH *back-end* allows instant interaction and real-time notification, and provides features for social network integration and streaming discussions. In addition, DRHH *back-end* provides additional custom-built REST interfaces i) to support other tools in RRE in accessing constantly updated information, even in (near) real-time, if necessary, such as the DSS, and ii) to retrieve content filtered by categories from the DRHH database.

3.4. Processing and filtering data and strategies

The information collected from the case studies during the first phase of the project enabled a detailed analysis of heritage-led regeneration processes. The *role models* were systematically studied to extract key factors to offer methods and actions to capitalise on the cultural and natural capital of rural areas. Systemic Innovation Actions and Community Capitals Frameworks were used as harmonisation tools in order to build a multilevel database of best practices. The information was gathered through three campaigns and the knowledge was extracted and codified through an experience mining process to support the replication of the successful strategies. These analyses also allowed the identification of 70 common *lessons learnt*. This abstraction and conceptualisation of best practices have been included in a multilevel database as specific replicable strategies for replicators. Consequently, the database has codified information regarding *role models* at Systemic Innovation Action, process, specific action and lesson learnt level. A detailed description of the process and preliminary results can be found in Egusquiza et al. [15].. Based on these results, *replicators* are supported by the digital tools available in the RRE, including the DSS, which is a system for supporting the discovery and composition of possible heritage-led regeneration scenarios considering previous initiatives and providing suggestions for finalizing strategic actions.

In the methodology considered, the DSS combines the best practices and an Inventory of Lessons Learnt dataset, which includes the data gathered from various role models and processed, allowing the choice of comprehensive programmes to be implemented by other local stakeholders who aim to undertake a regeneration process. Fig. 8 shows the main Services distributed by the RRE which cooperate to compose the DSS.

The DSS Web Portal is a module designed to allow users to interact with the DSS through a web service page. Users are able to explore data from the datasets integrated in the RRE and make use of the multiple functionalities that the DSS provides for filtering and addressing new purposes.

The DSS Wizard functionality uses an internal data model combined with statistical, filtering and sorting mechanisms that were designed based on relevant features that were indicated by RURITAGE rural regeneration experts. For multiple scenarios, the results have been reviewed and approved by these experts and have been described as relevant with correlated information. This way the Wizard can make smart selections offering the user an initial good collection of information to start exploring. The local stakeholders (mainly replicators) have played as leading actors in validating its use.

Also, statistics of collections are provided to help users better understand the data and even explore further. A screenshot of the Wizard is presented in Fig. 9.

4. Results and discussion

In RRE users are engaged across multiple functionalities in the same digital environment (Atlas, Monitoring Platform, Digital Rural Heritage Hub, My Cult-Rural Toolkit, Decision Support System, Replication Toolbox). In RRE systems, identification-description, monitoring, engaging local stakeholders and supporting new strategies can be explored as separate but integrated functionalities to provide a broad interpretation in a dynamic vision of territories based on reliable information, from their history to current developments, as well as concrete actions.

Each tool's interface enables several specific functions by visualizing systems of a contextualised description, monitoring or providing skills, allowing the exchange of knowledge amongst peers, supporting decisions or providing detailed information about the possibility of replicating.

Furthermore, the RRE goes beyond a platform that includes parallel tools with their individual functionalities. It merges data from different sources by integrating existing data, data gathered and processed, and data developed by several different research developments. Data from institutional datasets and scientific research is merged with data collected using the bottom-up approach. By integrating tools, functionalities and all this data RRE enables a holistic digital and heritage-led knowledge of territories for actions. It fosters a user-centred heritage digital transformation of rural areas.

Lastly, the RRE enables a novel dynamic and evolving vision of territories with their ongoing change through time. Some functionalities within the ecosystem continue to feed and new external inputs can also be incorporated as the RRE is an open platform.

Within the research project, the RRE and its digital tools have been used as support in the definition of heritage-led regeneration strategies that aim for the sustainable growth of rural territories through CNH [9,41]. The methodology is shaped for implementing strategies, collecting and refining data in order to conceive and customize the tools for rural regeneration.

Specifically, as shown in Fig. 10, the RRE can accompany case studies in the whole process of identifying heritage values within territorial developments and designing heritage-led regeneration,

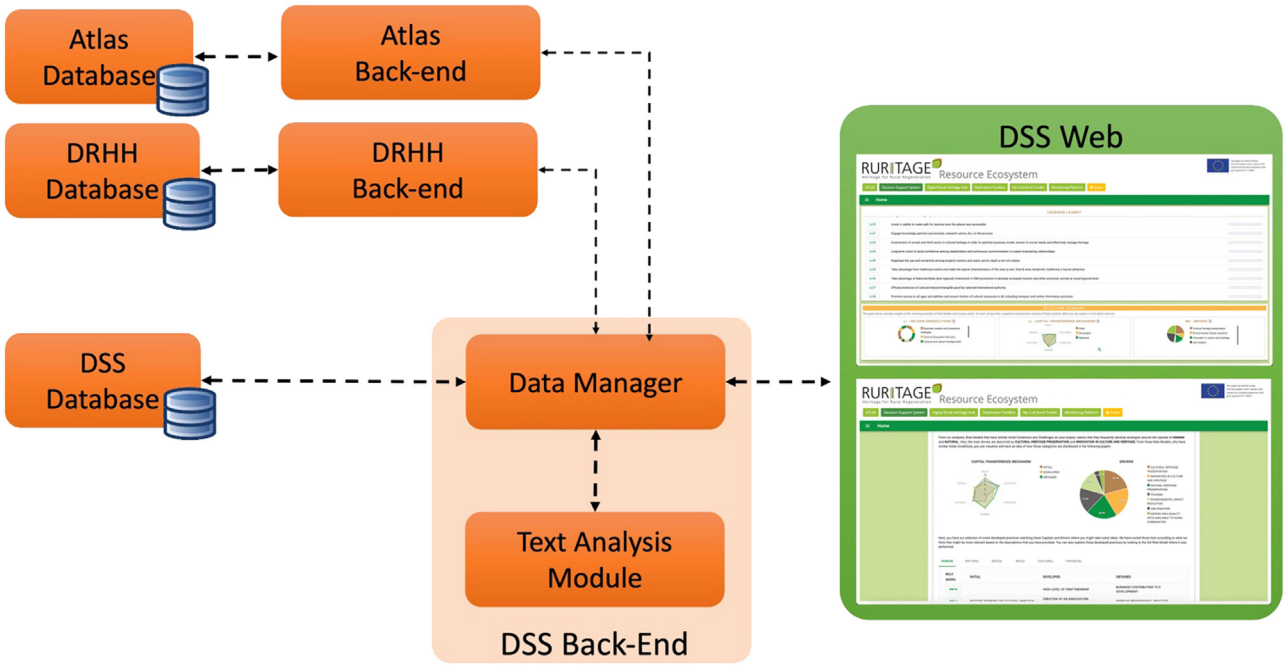

Fig. 8. RRE services in the DSS (decision support system) and their communication flows (DRHH: digital rural heritage hub).

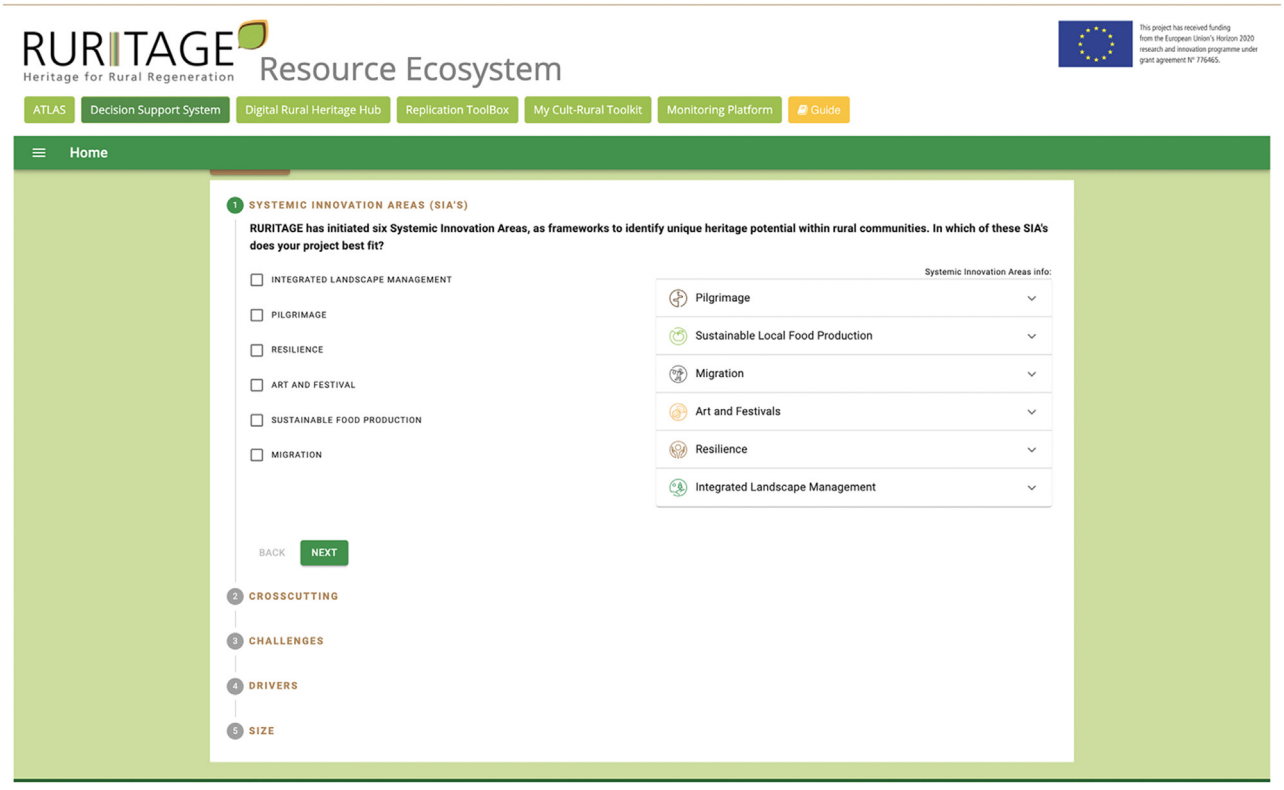

Fig. 9. The screenshot of the wizard of the DSS (decision support system) in RRE.

detailing the different phases of the process with the use of different digital tools.

- Diagnosis of a territory: the first step to be undertaken by RURITAGE case studies was the initial assessment of challenges and opportunities. This process made use of three digital tools of the RRE and supported their development: i) the Atlas, with various types of data and information regarding the historical development of local CNH and current cultural experiences with their dense relationships and open-source maps, provides a base of knowledge on the territory and current opportunities to build strategy. The Atlas also offers the chance to go beyond a static analysis, allowing the creation of interactive maps and scenarios that can aid the imaging of the development of the future. For instance, in the cases of the Comune di Appignano del Tronto and Izmir Geopark in Gediz-Bakircay Basins, a 3D

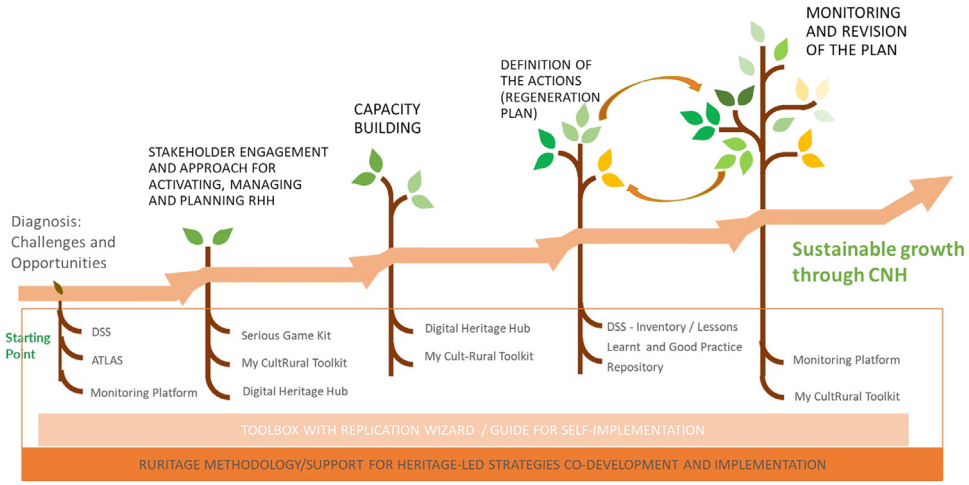

Fig. 10. Ruritage methodology/support for the co-development and implementation of heritage-led strategies.

model has been built to highlight the historic city centre and shed light on the impact of the earthquake in 2016 in the former case and to revive the ancient market of Pergama in the case of Izmir; ii) the Monitoring platform provides case studies with the definition of a baseline, based on a series of KPIs, which are then used to assess the effectiveness of the strategies in place; iii) the DSS provides inspiration based on filtering good practices and lessons learned in *role model* territories.

- Stakeholder engagement: a crucial step in the co-development and co-implementation of heritage-led regeneration strategies fostered by the research project is the involvement and engagement of stakeholders in the local Rural Heritage Hubs. While this process follows a structured approach in RURITAGE, some steps of the process are supported by the digital tools developed: i) the DRHH allows the creation of digital local communities that can communicate in a dedicated forum. This was particularly useful during the COVID-19 pandemic, when stakeholders were unable to meet in person for several months; ii) My cult-rural toolkit is a crucial element for stakeholder engagement, as it can provide a broader understanding of the perceptions people have of their local heritage and how these can change over time.
- Capacity building: networking and capacity building are crucial to the exchange of knowledge at different levels. While DRHHs at local level allow interaction amongst local stakeholders, the main blog of the DRHH aims to support knowledge transfer and capacity building amongst different case studies, creating interactions amongst players from different countries and contexts that can learn from each other and enrich their expertise. The interactive digital materials (webinars, pools, etc.) that populate the DRHH have contributed to this, supporting further learning and exchange.
- Definition of heritage-led regeneration strategies: in this phase, case studies mostly make use of the DSS, looking for good practices to replicate and lessons learned to be tailored to their territories. The DSS allows the selection of the most significant practices and lessons learned, based on the parameters identified by users. In this case, case studies can be directed towards the most suitable actions to regenerate their territories through heritage.
- Monitoring and revision of the plan: to assess the impact of heritage-led regeneration strategies and to build evidence on the effectiveness of this kind of strategies in rural areas, it is crucial to set up and implement a robust monitoring system. Within the RRE, the monitoring platform allows the monitoring of local heritage-led strategies of the *replicators* through the constant monitoring of pre-defined KPIs. This monitoring allows the tailoring of strategies based on their performance and the assessment of the cost/benefit of the actions put in place. Moreover, the My cult-rural toolkit helps gain more qualitative aspects of the strategy implementation, also in terms of perceived wellbeing and perception of local CNH.

As mentioned earlier, all the digital technologies developed within the RRE aim to support and enhance cultural heritage management, fostering a better understanding of heritage resources and unlocking heritage as a driver of rural regeneration. In this sense, the RRE develops digital and heritage-led strategies based on reliable and rich information.

Digital technology can foster the spreading and enabling of new socio-economic developments and more sustainable uses of our environment. Cultural heritage should be included as an essential cultural resource suitable also for improving socio-economic conditions and the resilience of non-urban areas for achieving heritage-led regeneration. Even though the use of digital tools could be hampered in rural areas, due to lack of digital skills and full availability of digital infrastructure, rural communities are advancing quickly in this regard, also in the light of and thanks to the new needs raised by the pandemic conditions [42] and the new policies developed at EU level [34].

RRE provides improvements in making both essential information and tools for co-developing specific information and strategic actions at local level available. As an integrated digital ecosystem in evidence-based and place-based regeneration strategies, it offers a wide range of case studies characterised by different CNH in different regions of Europe and beyond considered for systemic innovation actions. It provides tools for a multilayered overview of their features and values, in a historical and physical context, and strategic analysis for identifying current potential and solutions as well as tools for making concrete choices and actions.

All users can take advantage of RRE by interacting tool by tool, as it is open to exploring how these successful practices of CNH management can be and have been replicated. Stakeholders can understand how to become leading actors of new regeneration processes in their areas and, thanks to the Replication Toolbox, they can be ready to replicate the process.

It should be noted that no tools have been conceived to allow users to directly add and update information. This could be understood as a limitation. Further developments could allow direct input from users with a validation process.

Tools have been created with information gathered and co-developed with role models and replicators (e.g.: the Atlas by co-mapping) and tested by the actions of replicators and the RURITAGE community at large. According to RURITAGE methodologies which need local specifications, RRE requires tool developers (with knowledge facilitator partners), engaging new local stakeholders to implement new case studies.

For all these purposes, RRE provides a user-friendly digital environment including tutorials for the use of the tools and a guided process throughout the digital and non-digital methodologies of the RURITAGE project, to understand how to interact with RRE and with the RURITAGE project.

5. Conclusion

A digital and heritage-led holistic knowledge of rural regeneration requires a novel vision based on a strong integration of approaches and tools.

The integration of tools in a resources ecosystem needs to consider different tools developers using different software products and applications developed in parallel, and the various updates needed for their finalisation. The information was also shaped in parallel with the finalisation of the tools, with intense collaboration amongst tool developers, facilitator partners, *role models* and *replicators* as data providers and testers. Beyond and before any technical ICT solutions, this required a strongly integrated multidisciplinary approach to be taken by heritage humanities experts to conceive a digital environment for a heritage platform as a whole and make it user-friendly and suitable also for non-experts. The final outcome also stems from a strong integration of historical knowledge of CNH and territories with operational data and solutions for management requirements.

The necessary cross-fertilisation and intersectoral collaboration between ICT experts (requiring "complete" information for customizing tools) and humanities fields experts (gathering data and processing information from different data sources and for different purposes with progressive improvements), is challenging. This paper includes humanities and ICT contributions with their different terminology and scientific understandings and references, illustrating the challenge of this collaboration and its scientific outcome across the H2020 research project.

Multidisciplinary cross-fertilisation fostered the achievement of a novel holistic user-centred digital ecosystem for heritage by supporting the digital transformation of rural areas. It will contribute to using integrated heritage knowledge to conceive the heritage-led regeneration of rural territories by fully exploiting the potential of a digital society, from the significance of their past and present conditions to the consistent developments of their future.

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