Framework for Data Analysis in the Context of the Smart Villages

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Abstract. In recent times, the digitalization of urban areas has got considerable attention from the public. As a side effect, there has also been great interest in the digitalization of the rural world or the so-called Smart Villages. Smart Villages refer to the improvement of infrastructure management and planning to fight against depopulation and low population density as well as the cuts and centralization of services supported by digitalization efforts. In this work, we present our research to build a framework for the analysis of data generated around the project Smart Villages, which is a joint effort to digitalize rural areas in the context of the Alpine Space. Our goal is to build a system to help local authorities to pilot a smooth transition into this new concept of the village.

Keywords: Data Analysis, Digitalization, Smart Villages

1 Introduction

It is widely assumed that the digital revolution and new technology's prospects have fundamentally changed the way we live in recent decades. In this regard, it is worth noting a recent and growing interest in the concept of digitalization of urban and rural areas [7]. Although until now almost all research activity has been focused in the urban areas, e.g. the so-called Smart Cities [3], little attention has been paid to the rural world [21]. The truth is that the Smart Cities are able to generate a huge amount of data that makes the discipline very attractive for dealing with problems related to Big Data and Artificial Intelligence. Some practical examples are the intelligent regulation of traffic lights, the automatic management of parking spaces, the intelligent management of urban solid waste, the optimization of mechanisms for energy saving on a large scale, the development of methods for collaborative transport, the intelligent communication between vehicles, the automatic methods for smart surveillance, etc.

All these problems, due to their data-intensive nature, have no direct application in the rural world, where data generation is not so frequent and is much more dispersed and fragmented. This makes the challenges of different villages having different conceptual frameworks [24]. For example, the rural world is experiencing a series of problems that if managed in time can be prevented from getting worse [15]. To name just a few problems, depopulation as a consequence of rural exodus, where many people leave the place where they have lived during many years in search of new opportunities in the urban world. The aging of the population, related to the previous point, as young people consider that other more populated places can be more attractive and offer more professional opportunities. Or the disappearance of public services, because it becomes very expensive to offer a service that will not have a large number of users.

The main goal of this work is to build a data framework associated with an online platform[1] intended to trigger the revitalization of rural services through digital and social innovation. In fact, our work is intended to support the automated analysis of a wide range of scenarios related to rural services such as how health care [8], social services [22], technology [11], energy [20], employment [12], transport [18] or retail [14] can be improved and made more sustainable through the use of information technology tools as well as community initiatives.

As an outcome of this analysis phase, it should be possible to proceed with the dissemination of practical guidelines that can be used in the conceptualization and development of smart villages. In parallel, the platform for linking the various initiatives is being maintained with the purpose of becoming an open space where to discuss and exchange ideas that can contribute to the correct development of rural areas. Therefore, our contribution here is the design and implementation of a framework for data analysis to pilot an appropriate transition to the Smart Village concept. To do so, we make use of a set of tools as well as several external knowledge bases that help us to automatically analyze the current state of a specific village in relation to a key set of attributes defined by an international community of experts in the field.

The remainder of this work is as follows: Section 2 overviews the state-of-the-art regarding existing data analysis approaches in the context of the Smart Villages. Section 3 presents the technical details of our framework including how we have proceeded to implement some interesting functionality: self-assessment, matchmaking, fake form detection, clustering, similarity calculation, and ranking. Section 4 presents a discussion about the possibilities that our framework offers to improve many aspects related to smart villages and it exposes in a concise way the lessons learned that can be extrapolated to a number of application areas that present a similar context. Finally, we remark the major conclusions of this work and possible future lines of research in Section 5.

[1] https://smart-villages.eu

2 State-of-the-art

Firstly, it is necessary to remark that there is not one clear and global definition of what a smart village is. There have been several attempts to provide a definition. However, there is no common agreement among the authors as to which attributes should be covered by such a definition. Zavranik et al. state that the reason for not having a simple unique definition is related to the fact that the communities from the rural world are not just an entity, inanimate and unchangeable, and are thus always dependent on the environment and changes in social and cultural structures [25]. In this paper, we believe that a fairly simple but also effective definition could be to consider smart villages as communities in rural areas that use innovative solutions to improve their resilience by leveraging their local strengths and opportunities.

What does seem to be clear is a list (probably not exhaustive) of use cases or scenarios that should be possible to easily implement in a smart village. Some examples of these scenarios are: a) creating new housing alternatives and opportunities [6]; b) making both energy generation and consumption more accessible [17]; c) improving the sense of community [9]; d) preserving important environmental zones [10]; e) connecting new and existing developments [23], and so on.

It is necessary to remark that there are already many initiatives in the context of Smart Villages. For example, the IEEE Smart Village program aims reducing the urban-rural breach [4]. Intending to reduce the gap between rural and urban areas and promoting the rural economy, the European Commission has also given priority to the development of Smart Villages within its agricultural policies, as well as in other plans related to specific research programs, for example the SIMRA project[2] and the ERUDITE project[3]. Moreover, Digital India has put the focus in rendering services to citizens in India. This focus plans for convergence of all services through a digital hub [5].

Besides, it is possible to find some works in the technical literature that allow to envision some urban-rural collaboration. For example [2] and [16]. However, there is a lack of field-oriented systematic methods and tools to guide and monitor the evolutionary process of the villages to higher smartness maturity levels. In fact, at present, this process is so unstructured that most local authorities do not have a starting point and guidelines that support them in making adequate progress in terms of smartness maturity. Therefore, the contribution represented by our work aims to fill this gap.

Within the context of our previous work, we designed a pilot system that aims to help the rural world identify its strengths and weaknesses concerning the degree of innovation in several different but complimentary areas [1]. The reason for this pilot system was to provide an effective and efficient tool for local authorities in villages to later help them pilot their transition to much more sustainable and intelligent models that will help combat some of the problems

[2] http://www.simra-h2020.eu/
[3] https://www.interregeurope.eu/erudite/

they face. This system was based on the concept of a questionnaire. The latter was specifically designed by a European committee of experts and tries to measure in an objective way the degree of maturity of the area to be investigated from six points of view, which although different, have a great relationship between them. These perspectives are economy, governance, mobility, environment, people and living. Now, our recent development will allow local authorities to effectively interact with the village and facilities as well as to monitor the village's developments.

3 Towards a Framework for Data Analysis

In our previous work, we built an online community around a Digital Exchange Platform (DEP) which as its name suggests allows the exchange of information and communication between all the villages, municipalities, or towns that wish to register. This community can be very useful to communicate experiences, ask questions, or simply keep in touch with a multitude of peers that share the same concerns when it comes to digitalization. However, this platform lacks a framework for the analysis of the data generated by the users. Now we have designed and implemented this framework.

To do that, we have based our solution on an architecture oriented to the deployment of microservices [19]. The advantage of an architecture of this kind is the capability to deploy applications as collections of loosely coupled services. Some additional advantages of this kind of architecture are: the microservices are easier to maintain and test, and they can be independently deployed. In this way, our solution allows the rapid and reliable delivery of services. Let us see each of the implemented components.

3.1 Self-Assessment

The main goal of the smartness assessment component is to identify the smartness maturity level of a given village based on the six dimensions proposed by the smartness model [13]. Based on the smartness questionnaire and context metadata entered by an assessor, potential possibilities of improvement are identified. The key outcome of the smartness assessment lies in the possibility of capturing the current status of a village in terms of smartness, as defined by the six smartness dimensions and within the boundaries of the specific assessor's knowledge, and in the possibility of creating targets for improvement in terms of smart transformation, as detailed in the following sections.

Smartness questionnaire The smartness questionnaire is divided into two main parts, i.e. one devoted to the questions intended for collecting metadata, outlining the basic characteristics of the evaluated village, and evaluation questions. The second part is devoted to collect the metadata that outlines the basic characteristics of the village being evaluated and of the assessors themselves. The key attributes used in the questionnaire are:

(1) **name of the village**,
(2) **country** in which the village is located,
(3) **kind of village** (choice: city — village — municipality — local area),
(4) **number of inhabitants**,
(5) **assessor age** (choice: youth — elderly — students — active working people),
(6) **assessor type** (choice: policy maker — academia — business).

The second part of the smartness questionnaire is 24 evaluation questions, divided into six dimensions. For each question, the assessor chooses one of the four offered options, and optionally, also provide a comment. In this context, after having filled in the fields related to the metadata and all the questions related to the six dimensions under study, the result is calculated. The smartness model [13] is able to predict the following smartness dimensions: Smart People, Smart Governance, Smart Living, Smart Environment, Smart Economy, and Smart Mobility.

The result is used for two main purposes. On the one hand, to show the visualization of the assessment using a bar chart and calculate the statistics that will allow the local authority to have a much more detailed vision of the current situation of its village. And on the other hand, to start a matchmaking process with other villages or areas that are already included in the system.

The smartness assessment solution consists of independent systems (i.e. smartness assessment and matchmaking) and knowledge bases (i.e. the collection of good practices and toolbox methods). To provide flexible and technologically independent communication between subsystems and knowledge bases, REST API is used as an interface between subsystems of the solution. The use of REST API technology ensures a high degree of interoperability in terms of data exchange, while at the same time provides the independence in technology selection.

After the process is complete, the assessment model can be visualized, printed or exported. The smartness assessment process involves activities that offer a set of pre-established good practices and tools to bring similar practices into the real world.

3.2 Best practice recommendation

Another key feature of our framework is the matchmaking between villages whose information is entered into the system. The matchmaking is done after the village's information is inserted with the help of the smartness assessment questionnaire, the level of smartness that this village has is calculated. The smartness of the village is shown as a distribution around the six thematic dimensions, which is useful in order to expose the use cases or good practices. To do that, we have designed a mechanism based on a microservice-oriented architecture that is capable of calculating the most related scenarios.

In the end, the output of the matchmaking process is an ordered list of recommendations adapted to the profile of an assessor and the context of the smartness of the village. One or more suggested recommendations consist of good practices that have previously been established in the region and have been proven to work in real-life scenarios. Beside good practices, recommendations also offer useful methods and techniques that describe guided approaches to achieve the goals set. The results are represented as we can see below.

```
{
"metadata": {
    "name": "string",
    "country": "string",
    "kind": "string",
    "number_of_inhabitants": 0,
    "assessor_age": "string",
    "assessor_type": "string"
},
"smart_assessment": {
   "smart_people": 0,
   "smart_governance": 0,
   "smart_living": 0,
   "smart_environment": 0,
   "smart_economy": 0,
   "smart_mobility": 0
 }
}
```

And then, we will get the answer:

```
{
    "id_good_practices": ["id", "id",...],
    "id_toolbox_method": ["id", "id",...]
}
```

Where the id is the unique key for each of the good practices so that

```
{
"goodpractices":[
{
 "id":2202,
 "title":"test",
 "short description":"test",
 "country":"Slovenia",
 "region":"test",
 "town": {
    "address":"Koroska cesta 46, 2000 Maribor, Slovenia",
                "latitude":46.5590355,
                "longitude":15.6380735
        }
}
```

The matchmaking process This process of matchmaking is carried out following the sequential steps. Firstly, the process identifies the good practices that are oriented to the type of user who has filled in the form, and secondly, filters out good practices that are oriented to the subject matter in which the assessed village has obtained the worst results. In this way, the user has access to very valuable information that will allow them to inform themselves and reflect on why other villages or areas have been able to progress in that particular dimension. The output of the matchmaking process is a list of recommendations that are fitted to the profile of an assessor and the calculated smartness of the assessed village.

The suggested recommendations consist of good practices and methods and techniques. While good practices represent illustrative examples already established in the region that have been proven to work in real-life scenarios, methods and techniques describe guided approaches to achieve the goals set by the village.

The knowledge base of good practices represents a collection of good practices from the domain of smart villages that have been proven in practice over the years and collected in the regions of the special scope of the project. Each of the good practices in the catalog is described by mandatory and optional attributes. The key attributes are:

(1) **Title of the good practice** – meaningful title of the good practice,
(2) **Short description** – concise description of the good practice,
(3) **Country** – country of origin,
(4) **Region** – region of origin,
(5) **Town** – town of origin represented by the pin on a map,
(6) **Category of smart dimension** (choice: Smart Economy — Smart Environment — Smart Governance — Smart Living — Smart Mobility — Smart People),
(7) **Applicable in rural, non-city areas** (choice: Yes — Maybe — No),
(8) **Region level** (choice: NUTS 1 — NUTS 2 — NUTS 3),
(9) **Affecting – scale** (choice: Village — City — Municipality — Local Region),
(10) **Affecting – population** (choice: Youth — Elderly — Students — Active Working People),
(11) **Timescale** – start and end date of duration of good practice.

3.3 Fake form detection

One of the most severe problems we have to face when working with data from smart villages is being able to automatically discern the veracity of the information to be analyzed. For example, in our framework, we capture a lot of data and information through questionnaires specifically designed to determine the degree of smartness of a given village. These forms are open to the public, and anyone can fill out the information truthfully or can do so without much thought, in a hurry, or without knowing for sure if the information they are entering is completely true. For us, it is extremely important to have the most reliable information possible, otherwise, the conclusions of our analysis run the risk of not being accurate. For this reason, we have been working on an automatic mechanism capable of verifying the plausibility of the data inserted into the system using different machine learning techniques.

Our solution is based on the notion of automatic classification which is a process intended to predict the outcome from a dataset that has been previously labeled by an human expert. In this case, we face a binary classification problem since there are only two classes: the filled form is valid or is not valid. In order to do that, the method needs to use some training samples to understand how the given input variables relate to the output values. If the automatic classifier is trained properly, it can be used to detect the validity of new data inputs. In this context, there are many automatic classification methods publicly available but it is not possible to conclude which one is the best. Most of the time, it depends on the application and nature of the dataset. For this reason, we have tried several methods here with their standard configuration.

The dataset Our dataset[4] has been compiled from a sample of 210 forms that have been filled out online by anonymous users. Many of these questionnaires are not serious because it can be clearly seen that many questions have not been answered or that many comments are meaningless. Or even because such a village does not exist or the metadata provided does not correspond to that of the village in question. Therefore, we have eliminated the empty forms and the repeated forms, and we have manually labeled the rest with the possibility that it is valid or not. From that sample, we are already able to apply some machine learning techniques that are capable of recognizing the patterns of the valid forms, so that in the future only these are processed, and therefore, the conclusions drawn are not altered by erroneous information.

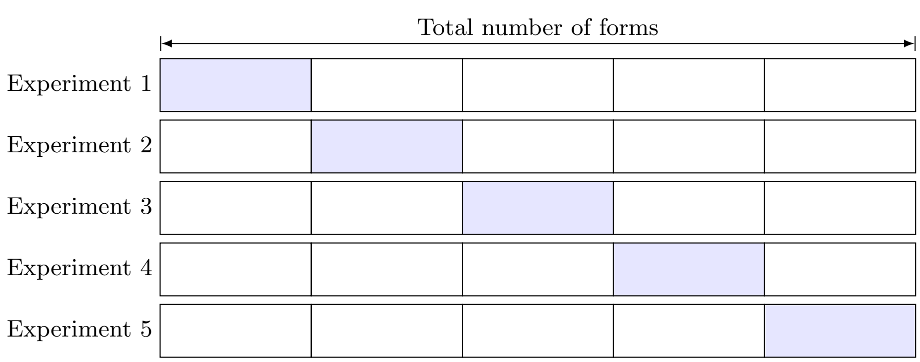

Fig. 1: Example of 5-fold cross validation

[4] https://smart-villages.eu/services/api/smartness

It is necessary to note that over-fitting is a common problem that can occur in most trained models. To avoid that, k-fold cross-validation can be performed in order to verify that a given model is not over-fitted. In this work, our dataset has been randomly partitioned into 5 mutually exclusive subsets to assure the predictive capability. This kind of cross-validation is commonly used in practice to compare and select a model because it is easy to understand and provides results that generally have better predictive capabilities than other approaches. Figure 1 shows us an example of how to proceed.

Support vector machines (SVM) are a set of supervised learning methods used for classification. SVM aims to smartly generate a hyperplane which separates the instances into two different classes: legit or not legit. The advantages of support vector machines are that they are effective in high dimensional spaces which is actually our case.

The k-nearest neighbors (KNN) algorithm is a simple supervised machine learning algorithm that can be used to solve classification problems. It works by scoring the target sample with the most common value among its k-nearest neighbors.

Random forests (RF) or random decision forests are a machine learning approach for automatic classification that operates by constructing a number of computational decision trees at training time and providing the result that is the mode of the results issued from all the decision trees.

Multi-layer Perceptron (MLP) classifiers stand for Multi-layer Perceptron classifiers. Unlike other automatic classification algorithms, it relies on an underlying Neural Network to perform the task of classification what usually leads to very good results although the interpretability, i.e. the ability to understand how the model works, is usually low.

Results We present here the results that we have obtained from our experiments. These results have been obtained after ten independent executions of each of the classifiers. The results are shown in Figure 2. As the process of dividing the dataset into training and test sets is done randomly, different results are obtained for each of the different executions. The way of representation through box plots allows visualizing efficiently the distribution of the obtained results.

As we can see in Figure 2, it is not always possible to identify if a form is legit. However, our classification models are able to achieve quite good results, being able to exceed 90% accuracy most of the times and even reaching values close to 95% in some situations. Therefore, we can conclude that our methods are capable of identifying a valid form with a fairly high probability. This will increase the quality of the final results and, therefore, the veracity of the conclusions that can be drawn from those results.

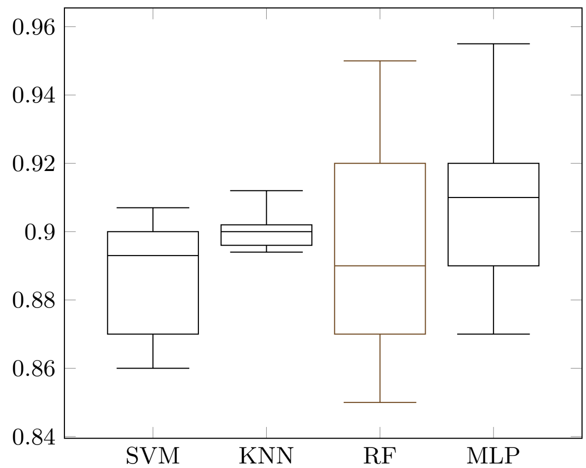

Fig. 2: Results of the four different classifiers for solving the problem of detecting fake questionnaires. SVM = Support Vector Machines, KNN = K-Nearest Neighbor, RF = Random Forests, and MLP = Multi-layer Perceptron

3.4 Clustering

One of the most interesting capabilities that our framework for data analysis can offer is to automatically calculate the clusters or logical aggregation of villages that share a similar degree of smartness either in general or in specific thematic areas. In our specific case, clustering is a data analysis technique whereby given a set of villages (represented by values stating the answers to the questionnaire), we can classify each village into a specific group. In this way, villages that are in the same group should have similar properties, while villages in different groups should have highly dissimilar features.

To do this, we proceed with the application K-means clustering algorithm that considers that each of the answers given by users is a different feature. Then, it aims to partition the villages into k clusters in which each village belongs to the cluster with the nearest mean. The set of answers given by each village represents the feature vector of that village from which the mean will be computed. It is possible to run the algorithm with different k parameters, and obtain results that have an obvious practical interest since it allows us to logically group the villages in the Alpine space that are more similar.

Figure 3 shows an example of 2-means clustering where it seems that the dimensions concerning economy and environment are not very overlapped. In general, it is possible to perform this kind of analysis to gain some valuable insights from our data by seeing what groups the villages fall into, and take decisions or elaborate policy tools accordingly.

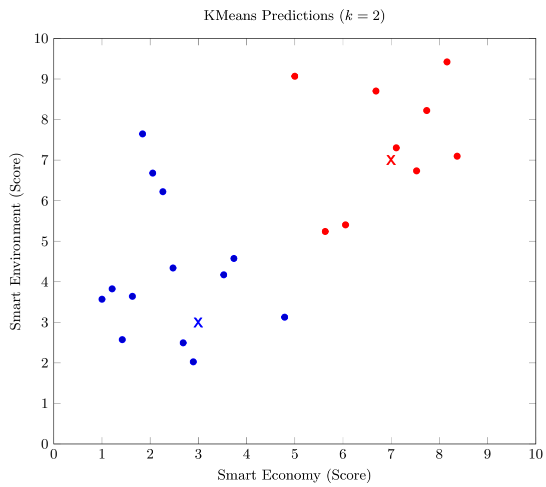

Fig. 3: Example of clustering of villages registered in our system

3.5 Similarity calculation

Another feature we have implemented in our framework is the automatic calculation of the similarity between villages. Of course, this is not a physical similarity, but a type of similarity that measures the degree of maturity in relation to each of the six dimensions of study that we address in the framework of this work. The calculation of similarity is very useful because it allows the local authorities of the rural world to determine which places present some characteristics to those of the place in question, so it is possible to look at them as a third-person viewer and analyze what actions they are currently developing. The similarity can be calculated as follows (being **A** and **B** the answers associated to the source and target village respectively)

$$\textbf{similarity}(\mathbf{A},\mathbf{B}) = \frac{\mathbf{A}\cdot\mathbf{B}}{\|\mathbf{A}\|\|\mathbf{B}\|} = \frac{\sum\limits_{i=1}^{n} A_i B_i}{\sqrt{\sum\limits_{i=1}^{n} A_i^2}\sqrt{\sum\limits_{i=1}^{n} B_i^2}}$$

The results of the comparison are something like we can see in the following portion of the code. Please note that the results are presented in a semi-structured format to facilitate automatic processing by a computer.

```
<?xml version="1.0" encoding="UTF-8"?>
 <results>
 <similarity>
  <villageA>Maribor</villageA>
```

```
  <villageB>Hagenberg</villageB>
  <score>0.8359</score>
 </similarity>
</results>
```

This similarity measure is just a statistical measures based on the calculation of the overlapping degree between answers given in the self-assessment test. Therefore, the resulting score does not have any additional connotation.

3.6 Ranking

The ranking functionality is related to the creation of an ordered list of villages to facilitate the understanding of specific factors. By reducing detailed features to a sequence of ordinal numbers, the ranking functionality makes it possible to assess interesting information according to some specific criteria. But since the results only show the perception that the local authorities have about their village, these results must be taken with caution.

The following listing shows us an example of a ranking for the category Smart Living extracted from our system. The listing has been generated in a semi-structured format to facilitate automatic processing.

```
<?xml version="1.0" encoding="UTF-8"?>
<SmartLiving>
  <village name="Maribor" points=11 category="B"/>
  <village name="Hagenberg" points=11 category="B"/>
  <village name="Wattberg" points=10 category="B"/>
  <village name="Linz" points=10 category="B"/>
 </SmartLiving>
```

It should also be noted that the granularity of the results is not very large, so perhaps the category gives more information than the numerical value itself.

4 Discussion

Most rural areas in many developed countries are facing a major transition related to digitalization. Some of the most interesting aspects of this transition are how current facilities are going to be adapted to work with low-carbon demand or how some of the existing solutions can be integrated into the circular economy. In this context, it could be of great help some tools to guide the digital transformation of the rural economy, and even some guidelines to create positive relations between villages and cities

So far, most of the technological advances made in recent years have benefited urban areas. In this way, novel methods and tools based on Big Data techniques and Artificial Intelligence have greatly benefited the development of the so-called Smart Cities. However, rural areas have not benefited as much from technology until now. With our work, we have attempted to do our bit for the development of methods and tools to fight some of the problems that plague rural areas. We think that rural areas can benefit equally from all scientific and technological advances, but the right framework must be in place so that these solutions can make sense and help local authorities to manage a transition that is appropriate to their needs.

Also, the Smart Village model seeks to change conventional rural industries such as agriculture, livestock, mining, etc. by implementing innovative approaches for smart data processing. In this manner, new concepts linked to sustainability and productivity become very relevant and give rise to new types of business models.

5 Conclusions & Future Work

In this paper, we have presented our framework for data analysis in the context of the smart villages. Our goal is to develop novel methodologies and tools that will help local authorities in the rural world to pilot an appropriate transition to an effective and sustainable digitalization model that will handle some of the problems that they are currently facing.

In this context, we think that our framework can successfully help to manage a wide variety of data that can be captured from our online platform. Examples of these data are collections of the current status of a village, including metadata about the person that fills the questionnaire and the answers to the questions performed to prepare a smartness assessment report. Recommendation of good practices so that experiences that have taken place elsewhere could be applied in the place of the person or local authority receiving the recommendation. Fake form detection, because when working in an open environment, there may be situations where the information entered is not legit and therefore may lead to wrong conclusions about the situation of the village. Clustering of villages so that interest groups that share certain peculiarities and characteristics can be identified automatically and without human supervision, and for whom joint action could have meaning and great advantages. Calculation of the similarity between villages that are registered in the system, so that it is possible to better understand which places share common characteristics. And last but not least, the automatic creation of rankings to support decision-making aimed at improving the quality of life and the revitalization of rural environments.

We think that our work concerning the development of new methods, tools and frameworks for data analysis in this context will facilitate a transition into the concept of Smart Villages. At present, this transition lacks proper guidelines and tools, and it is so unstructured that most local authorities do not have a starting point nor software support to guide them in making adequate progress in terms of smartness maturity. However, this is only the first version of the framework. And we propose an iterative life cycle to improve it based on the experiences and suggestions provided by the users.

As future work, we would like to work on interoperability with a toolbox component. That toolbox component would be a repository to organize a number of existing tools or methods in the context of the digitalization of rural areas. The idea is to help local authorities to pilot a smooth transition into more sustainable models. In addition, we would like to add more collaborative features, at this time we can analyze a snapshot by village or test area, but we would like to design novel methods to determine the degree of smartness of a given village. We would like to collect a multitude of opinions from a wide range of inhabitants, including local authorities, neighbors, businesses, etc. In that way, we think that the analysis would reflect reality much more accurately.

Acknowledgements

Authors would like to thank the anonymous reviewers for their help towards improving this manuscript. This work has been developed within the SmartVillages project, Smart Digital Transformation of Villages in the Alpine Space, co-funded by Interreg Alpine Space (20182021). The authors would like to express the appreciation to SmartVillages project members for their contribution.

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