www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

COLLABORATIVE INTELLIGENCE CYBER-PHYSICAL SYSTEM FOR THE VALORIZATION AND RE-USE OF CULTURAL HERITAGE

SUBMITTED: August 2017
REVISED: October 2018
PUBLISHED: November 2018 at https://www.itcon.org/2018/15
EDITOR: Turk Ž.

Andrea Bonci, Dr.,
Polytechnic University of Marche, DII, Ancona, Italy;
a.bonci@univpm

Paolo Clini, Prof.,
Polytechnic University of Marche, DICEA, Ancona, Italy;
p.clini@univpm.it

Rafael Martin, Dr.,
UrbeProOrbe Cultural Heritage, Spain;
rmartin@urbeproorbe.com

Massimiliano Pirani, Dr.,*
Polytechnic University of Marche, DII, Ancona, Italy;
massimiliano.pirani@gmail.com

Ramona Quattrini, Dr.,
Polytechnic University of Marche, DICEA, Ancona, Italy;
r.quattrini@univpm.it

Alexander Raikov, Prof., Dr.
Institute of Control Sciences Russian Academy of Science, Russia;
Alexander.N.Raikov@gmail.com

SUMMARY: *This paper is a proposition of methodological and technological approaches that try to constitute a framework that introduces modern artificial intelligence (AI) technologies for decision-making in the adaptive re-use of cultural heritage (CH) processes. The research aims to accelerate and improve the quality of adaptive CH re-use. The complexity of the problem derives from some causes of different nature: lack of attention to this problem from the public administration and private investors; decision-making processes complicated by the need to connect with experts, located in different countries. Most professionals, related to the CH management, cannot access detailed data about already existing successful initiatives. The specific objective and goal of the research is the creation of an AI framework and eco-system for supporting the development and implementation of innovative business and governance models to fill up the investment gap in the adaptive re-use practices. The paper shortly describes the first steps for creating a platform designed and developed to assist and advice public entities, networked experts, private entrepreneurs and citizens in actions aiming at the valorisation of the historic and CH asset and its integration in different groups of countries to boost growth, job opportunities and social benefits, under overall sustainability constraints. The technical solutions here adopted are based on convergent methodology and networked expertise (e-expertise) technology, open data models and active knowledge extraction and processing, machine learning, collective intelligence, recommendation systems and predictive analytics, CH adaptive re-use, innovation business, and models and case-based reasoning methods. Examples of case studies giving the inception for the project components are given.*

KEYWORDS: *adaptive re-use, artificial intelligence, assistant system, cultural heritage, decision-making, networked model*

REFERENCE: *Andrea Bonci, Paolo Clini, Rafael Martin, Massimiliano Pirani, Ramona Quattrini, Alexander Raikov (2018). Collaborative intelligence cyber-physical system for the valorization and re-use of cultural heritage. Journal of Information Technology in Construction (ITcon), Vol. 23, pg. 305-323, http://www.itcon.org/2018/15*

1. INTRODUCTION

The adaptive re-use of cultural heritage (CH) is a complex and deep problem. The complexity derives from:

- the different nature of the causes of lack of attention to this problem from the public administration and almost consequently from private investors;
- most professionals, related to the CH management, cannot access detailed data about already existing successful initiatives within this frame;
- decision-making processes are getting complicated by the need to connect with experts, located in different countries and working in a lot of thematic fields.

All of these items create an important barrier to the development of new and innovative solutions. Moreover, the set of possible actions and components of the solutions to try to intervene in is huge. To make things even worse, a particular action might not yield the expected return.

In complex system of systems, as a social networks and networked professional collaborations, supposedly good actions might generate disastrous effects as the decision-making processes have a divergent character. This is a well-known and well-perceived effect of social and group systems, in particular from politicians and governors who are tempted from inertia and rather mild actions to not "rock the boat". Public initiatives and strategies also frequently miss some of the stimulus that occasionally comes from civil society and associations or private entrepreneurs. On the other hand, potentially good top-down actions do not succeed in reaching and correctly stimulate people and professionals towards the desired targets. It frequently happens that funding initiatives do not achieve correct implementation when local authorities receive them. Growth and sustainability are difficult to be effectively addressed by funding strategies relying on a direct cause-effect approach for the actions in the field. It usually generates waste of public resources if not completely adversely dangerous effects in the medium term.

The former motivations draft a clear demand for the creation of a specific collaborative project for the design of an information and communication technology (ICT) framework and eco-system for supporting the development and implementation of innovative business and governance models. To fill up the gap in the adaptive re-use practices, a special methodology and technology platform has been created (further in the text - the Project). The Project was designed and developed to support networked collective decision-making, to assist and advice public entities, private entrepreneurs and citizens in actions aiming at the valorisation of the historic and CH asset and its integration to boost growth, job opportunities and social benefits under overall sustainability constraints. Beyond the effective informational gain provided and expected by a suitable Web-based open platform, the Project attacks the problem of the introduction of Artificial Intelligence (AI) and networked expertise (e-expertise). Such an experiment is new in CH context and is conceived to produce an enduring and effective technology transfer channel between the advanced AI research and the impact on global society.

Moreover, social acceptance of efforts and costs for preservation and adaptive re-use of CH should be based on its enhancement through digital tools, in particular this is mandatory for the widespread CH. In this field, the adoption of digital surrogates enables the CH workers and experts in remotely preventing, monitoring and planning interventions about CH decay.

The paper faces two connected problems: the cultural heritage re-use and the availability and re-usability of rich digital data in CH domain. The case studies highlight the preliminary analysis about specific key performance indicators (KPIs) to be boosted and validated in further steps thanks to the development of the net-worked expertise technology. To develop such analysis, the authors have taken advantage of their experience within the field of conservation, management and re-use of cultural heritage buildings. In particular, some of them have participated in the Masterplan for the Conservation of Alava's churches, funded by both the Regional Government of Alava and the Bishop of Alava. Such work was based on an innovative management approach whose key points were the territorial analysis of cultural heritage based opportunities for the social and economical development as well as the re-use of historical buildings as the main issue for their proper conservation. Such previous knowledge has been crucial to deal with the current study.

2. CULTURAL HERITAGE GOVERNANCE AND DIGITAL CULTURAL HERITAGE RE-USABILITY ISSUES

The CH governance situation is characterized by a growing need for the adoption of approaches and tools that lead to stronger strategies for the preservation and valorisation of CH through its sustainable adaptive re-use. This will impact favourably on growth at citizens', private companies and at governmental level. As some surveys (Rypkema et al., 2011) demonstrate, nearly 15 new local jobs are created per million of expenditure on the rehabilitation of a historic structure. Moreover, incomes are typically a 30% higher for heritage tourists with respect to non-heritage tourists. Nevertheless, those and similar positive effects on economic growth have to be stimulated under proper control. UNESCO warns that complex interactions occur between heritage sites and the stress due to pollution, urbanization, tourism and climate change (Markham et al., 2016).

The re-use of cultural heritage buildings is a fundamental key for their latter sustainable conservation. A building with no use or with an inadequate one is roughly difficult to preserve in terms of cultural, social and economical feasibility. For this reason, the search for creative and innovative ways to boost adaptive re-use of such buildings and sites is becoming an essential goal to reach within the frame of cultural heritage management.

2.1 Relevant cultural heritage projects and status

As some recent projects demonstrated, a recurring focus lies in sustainable issues and retrofitting solutions or interaction between historical heritage preservation at different scales and climate change. For example, the EU FP7 Climate for culture project (www.climateforculture.eu) presents methodologies developed for the assessment of climate change impact on collection objects in cultural heritage buildings (Rajčić et al., 2018). Among the more relevant EU Horizon 2020 and EU FP7 projects, 3ENCULT (www.3encult.eu), RIBuild (http://ribuild.eu), and A2PBEER (http://www.a2pbeer.eu) bridge the gap between conservation of historic buildings and climate protection, developing solutions that insure to maintain them as living space also with guidelines for thermal insulation. Those projects deal with CH re-use through energy efficient retrofit for structural protection as well as for comfort reasons.

The increasing of population produced an enhancement in demands of resources, but at the same time, the massive land consumption should be kept under control. For these reasons, many abandoned historical palaces could be reinterpreted to overcome new functions. This is an efficient use of the palaces, which not only helps to prevent historical site from decay but also preserves them in a better situation. The efficient re-use should be focused on the reincorporation of old materials to let the original building resume value and function. Unfortunately, a vast extent of total energy utilized globally is still contributed by the construction of buildings and their operations. Existing buildings have been noted to utilize more energy and still their replacement rate is only around 1.0–3.0% per annum, while retrofit rate of non-residential existing buildings is approximately only 2.2% per year (Jagarajan et al., 2017). On the other side, the management of CH has traditionally been connected with the identification, estimation, interpretation, organization, maintenance, and preservation of CH assets: churches, industrial buildings, abandoned farms, cultural landscapes, archaeological sites, CH monuments, etc.

The intangible aspects of CH, such as skills, cultures and languages are also important. Possible threats in CH management connect urban development, agriculture, mining deals, and erosion of tourists' number. The public face of CH management, and a main source of income to support development of heritage for presentation, is in the tourism business. Communicating with government, professionals' and experts' communities, and public is therefore one of the key factors.

The link between CH and tourism sector is sometimes neglected or difficult to make sustainable for little institutions. In order to answer to similar needs some projects were founded such as PLUGGY (www.pluggy-project.eu), LoCloud (https://locloud.eu), INCEPTION (www.inception-project.eu) or TagCLOUD (www.tagcloudproject.eu). PLUGGY is an ICT platform that aims to provide citizens and cultural institutions with the necessary tools to share their local knowledge and everyday experience with others, connecting the past, the present and the future. LoCloud's overall goal is explore the potential of cloud-computing services to help small and medium sized organisations in making their content online and accessible to users via Europeana (www.europeana.eu). INCEPTION (Inclusive Cultural Heritage in Europe through 3D semantic modelling) ranges from the documentation and diagnostic strategies for heritage protection, management and enhancement, to the 3D acquisition technologies. The development of hardware, software and digital platforms is aimed at representation and dissemination of cultural heritage through ICT processes and BIM addresses to CH assets, up

to the implementation of semantic information to a wider and more extensive use of 3D digital models. TAG CLOUD offers a new approach in developing truly personalised cultural experiences by seamlessly incorporating cloud-based (non-sensitive) information about the habits, preferences and motives of individuals into the digital content of a cultural objects (e.g. artefacts, buildings, sites, etc.). It allows to increase the users' interest for cultural heritage giving an active participation in the assignment of the importance of a cultural artefact. Similar approaches are rooted in the present research, as highlighted in the following in the Flaminia Nextone paragraph.

Another set of projects involved the dissemination of CH in Virtual Museums: ViMM (www.vi-mm.eu), EMOTIVE (www.emotiveproject.eu) or iMARECULTURE (https://imareculture.weebly.com/). ViMM (Virtual Multimodal Museum) improves understanding of new ways of taking into account the state-of the-art in cloud computing, smart technologies and big data management in order to enable discovery for Virtual Museums of European digital content which was previously inaccessible, buried among huge amounts of data and/or not sufficiently tagged with adequate metadata (ViMM, 2018). The principal objective of the EMOTIVE project is to research, design, develop and evaluate methods and tools that can support the cultural and creative industries in creating Virtual Museums which draw on the power of 'emotive storytelling'. This means storytelling that can engage visitors, trigger their emotions, connect them to other people around the world, and enhance their understanding, imagination and, ultimately, their experience of cultural sites and content. EMOTIVE will do this by providing the means to authors of cultural products to create high-quality, interactive, personalized digital stories. The scope of iMARECULTURE is to raise public's awareness on European identity by focusing in maritime cultural heritage, which by default bridges different civilizations. Project's actions aim to raise public awareness through serious games, prior and after the visit to an archaeological site or museum. In our cyber-physical methodology the contents generation, adaptive re-use of CH and their dissemination in Virtual Museums or, more in general, assets are strongly linked.

2.2 The proposed approach

The subject of business and governance of the CH re-use is connected with the processes of management, the decision-making and experts' assessments of the objects of CH, and the events related to these objects. There are a lot of expert-analytical organizations (Think Tanks) and decision-making technologies. Think Tanks are research analysts and engagement organizations that make research, analysis, and advice on domestic and international issues. Recently a certain process of decline of the number of Think Tanks has been noticed along with substantial changes in the technology adopted for support of their activity. Recent trend is in direction of development of networked processes, using collective and Artificial Intelligence methods. The reasons are as follows: globalization; increasingly information-rich environments; decreasing funding for research by public and private donors; the donors' tendency toward short-term, project-specific funding; retention of talents and resources during a leadership transition; increasing reliance on mobile devices, and etc. Under these conditions, traditional methods of expertise and assessments of CH are becoming increasingly less relevant and new methods of public engagement constantly emerge. This poses both a challenge and new opportunities.

In this situation, the new objectives become more important than ever, to tackle timely the evolutions of CH business, governance, assessments etc.

3. METHODOLOGY

This study begins with an analytical review of scientific papers, government and authority documents to find the goals of adaptive re-use of CH and major factors that impact on the decision-making processes in this thematic field.

The adaptive CH re-use issues have not been strongly advocated until now. Some of the following issues have been under investigation only in the last decade: the partnership scheme with NGOs to participate in decision-making, CH interference with sustainable urban development, systematic connection to the process citizens, using modern AI technology for decision-support.

3.1 Cultural heritage re-use goals

Analytical review of different papers and documents (Yung and Chan., 2012) shows that the CH re-use goals cover political, economic, social and technological fields. One of the major goals is achieving low carbon cities. Heritage buildings, as long as usual buildings, are responsible for energy use and produce greenhouse gas emissions. There

are some approaches for reducing the emissions including mitigation of carbon energy sources, technology innovation, and adaptation or behaviour change (Crane and Landis 2010).

The present paper is focused on the sustainable development support. Within this, the spheres of sustainability are also postulated so as: political-institution, institutions of the society, local political governance. It is important to support the balancing of the trade-offs and to resolve the conflicts between the spheres of sustainability.

Adaptive re-use may be defined as "any building work and intervention to change its capacity, function or performance to adjust, re-use or upgrade a building to suit new conditions or requirements" (Douglas 2002). In this context, the analytical review show that the lists of CH re-use goals could include:

- sustainable urban development;
- mitigation of the adverse impact of climate change;
- effectively tackling of climate change;
- extension of the CH building life;
- demolition waste avoidance;
- to encourage the re-use of the embodied energy;
- to provide significant social and economic benefits to the society;
- to create public-private partnership scheme for the revitalization of CH buildings.

Nevertheless, the existing approaches to goal setting do not completely cover such aspects of CH re-uses development as follows:

- to design and develop replicable and shareable tools;
- to determine means and structures for continuous knowledge acquisition and formalization;
- to achieve indicators for effectiveness and scalability of actions;
- to enforce barrier smashing innovation;
- to establish sustainability stewardship;
- to increase knowledge and values perception;
- to develop collective networked expertise technology;
- to encourage the re-use of the embodied energy.

At the same time, for making the achievement of these goals sure, different countries' governments' policies stress the CH development in its role in creating a quality of city and of the citizen's life. The revitalization and preservation has been advanced to maximize the economic and social benefits of CH. The main idea in the goal-setting is directed to the benefit and enjoyment of present and future generations.

3.2 Cultural heritage factors

The existing studies have identified many factors that impact on the studies that deem a CH building suitable or unsuitable for adaptation. However, the adaptive re-use of CH objects is more complicated than the re-use of ordinary buildings, given that they are not designed nor built with any standard pattern or predefined set of construction elements. Besides that, it should have minimal impact on the heritage significance of the CH and its setting, and adds a contemporary layer that provides some added value for the future (DEH, 2004). The significance and integrity of CH building can be threatened by poorly designed adaptations and mitigation responses. Thus, in the CH re-use, the interference with the fabric should be minimized. In addition, it should take into account the medium and long-term cultural and financial viability of the site. Although it is commonly believed that it is cheaper to convert old buildings to new uses than to demolish and rebuild.

The cultural heritage assessments are very difficult. Indicators and data formalization are still difficult to be universally defined in this field (Rypkema, and Cheong, 2011). They can comprise a desk-based study, interviews of the expert groups from different countries, and wide-area surveys. To add even more difficulty, there are many methods of decision making. For example, if we want to create strategic decision, there are something about 50 methods for decision-making support, while there are a few methods of assessment of the expert evaluation consistency. The paper (Yung and Chan., 2012) proposes and describes 20 sustainability factors shortlisted. The factors was identified from the literature and then verified by the experts in the interviews that were conducted

over a 3-month period with architects, property developers, project managers, heritage consultants, government officials, and NGOs. The factors were categorized into economic, sociocultural, environmental and political dimensions and include a wide range of sub-criteria. This is a bullet list of factors:

- Economic aspects:
  - Economic feasibility of the heritage place while achieving economic efficiency;
  - Capital costs of the building works, the future running costs of the proposed use, including maintenance costs;
  - Potential market for the proposed reuse, the location and the financial sources;
  - Tangible and intangible benefits of the project, including the direct and indirect economic incomes derived from both the exploitation of the CH object itself and the surrounding economic activity;
  - Job creation and the revitalization of the immediate area;
  - Social impacts on the community;
  - The increase in carbon emissions;
  - The extent to which the social and demographic characteristics of the local area affect project feasibility;
  - The types of development taking place locally;
  - The potential competition that may affect the existing businesses;
  - The sorts of services and transportation that are available;
  - Compliance with current building regulations such as means of access and escape, fire safety, planning and environmental regulations;
- Socio-cultural aspects:
  - Improving social inclusiveness and social cohesion;
  - An attachment to place and a sense of place;
  - Ensure the continuity of social life which contributes to the cultural significance of the place;
  - Strengthening of cultural traditions and forms;
  - Enhancing cultural diversity.
  - Reinforcement of the social identity values.
- Environmental and physical aspects:
  - Environmental upgrading of existing CH buildings of in-situ reuse;
  - Green adaptive reuse;
  - Environmental performance of a given design proposal;
  - Sustainability appraisal of historic building stock for mitigating some climate change effects;
  - Total amount of carbon emission in the built environment;
  - Adequate infrastructure for the whole area;
  - Access to public transport and major facilities.
- Political aspects:
  - Community participation in conservation efforts, which is reflected in the satisfaction rate of people in the conservation area;
  - Constraints, challenges, interests, and needs, etc. Of the affected parties and concerned groups in both public and private sectors;
  - Confrontations between decision makers and local citizens, and any social opposition to the finalized adaptive reuse proposal;
  - Effectiveness and transparency in the policies;
  - Strategies at the local level for sustaining the adaptive reuse of CH buildings;
  - Appropriate funding sources.

The number of factors could be increased. For example, the marked investigation can take into account consumers and engineering characteristics in details. Then the number of factors can be about one hundred (Gubanov et al., 2014). Evidently, there is an opportunity for the cyber-technology with an AI engine at the core. Machine learning methods and reasoners are a promising tool in order to improve the process of decision making about strategies, innovations, and the citizens regarding the adaptive re-use of CH. The set of the ICT and AI tools will support decision-making processes, networked expertise and bottom-up initiatives. By design, it has to be developed the special eco-system that will feature humanities and societies in the cyber loop whilst creating the links for opportunities across geographical and cultural borders. The tools have to be benchmarked against one state-of-the-art solution, and their performance assessed in case studies composed of use cases of different scale and nature.

For increasing knowledge and values perception, the relationship between historic preservation and economics for society is critical and needs to be provided on a regular basis. The research must be conducted on an academically robust level but, to be useful, must reach effectively the citizens and the potential stakeholders. Research findings and resulting recommendations need to be written so that they are comprehensible to preservation advocates, public servants, elected officials, and the general public. For networked expertise technology for CH re-used field the existing classical decision-making and expert assessment methods need to be developed on the base of networked expertise technology and AI (Gubanov et al., 2014).

3.3 Networked expertise technology (e-expertise)

The subject of business and governance of CH re-use is connected with the processes of management, decision making support, and group experts' assessments of the objects of CH and the events related to these objects. The CH objects are of several types, such as historical buildings (no matter whenever they have been built), historical urban environments, archaeological sites, cultural landscapes, etc. All the experts groups involved in the estimating phase will be required to fulfil a questionnaire on the quality of the outputs. The best form of the questionnaire will depend on the definitive semantic structure of the output information.

Culture heritage is not only a link to the past. It is the catalyst of current activity and support of the movement into the future. The destiny of every CH object is connected with many events. The costs for the adaptive re-use of these assets cannot be supported by the traditional public or private sector models. The peculiar process of CH re-uses demands the special market investigations, and every market segment could have many consumers' characteristics and factors (see section 3.2). This "gap" could be estimated by experts or groups of experts who incorporate innovative AI, business and governance models.

The questions have to be comprised into three groups: holistic, performance and sustainability (Raikov, 2016). This decomposition helps to get the convergence of decision making process (Raikov and Panfilov, 2013) and provide a high-level expert holistic discourse during decision making process.

A CH object could be characterized by various different quantitative, geometrical, qualitative, phenomenological, and etc. parameters. Some of the parameters could be latent or hidden. For example, the historical or archaeological places could be of cultural importance to a group of people who are not either historians or archaeologists, but they can potentially be interesting for them due to religious reasons. Moreover, in case of archaeological research takes place on the site of CH, the decision making process about re-using of the object can be delayed to allow evaluation of the site. It implies participation of experts from different countries and different activities.

Under these conditions, the correct assessment of CH object determines success of its current and future development. The CH experts' assessments can comprise a desk-based study, interviews of the expert groups from different countries, a wide-area survey. It could be groups (categories) of questions, as follows:

- Cultural heritage object (C1);
- Property and management of the CH object (C2);
- Use of CH object (C3);
- Funding and economical resources (C4);
- Sociocultural environment (descriptive answers) (C5).

The initial fragment of questionnaire is illustrated by Fig. 1.

PTOLEMAUS

Dear expert!

We kindly ask you to take part in the survey of experts on the topic "The sustainable re-use of cultural heritage (CH)".

The moderator of the poll is the [....]. The CH object is [……].

The poll's Goal is raising quality of the governance and sustainable harnessing of the full potential of CH.

…..

CATEGORY 1 (C1): About the cultural heritage object.

1. What is the type of CH object (it may be the level of belonging to the one of the types of object)?

1.1. Building

Scale level	<<< Higher <<<		<*>	>>> Lower>>>		Difficult to answer
	Very high	High	Average	Slow	Very slow	
Scores	5	4	3	2	1	0

Comments (description):

1.2: Urban place

Scale level	<<< Higher <<<		<*>	>>> Lower>>>		Difficult to answer
	Very high	High	Average	Slow	Very slow	
Scores	5	4	3	2	1	0

Comments (description):

1.3: Archaeological site

Scale level	<<< Higher <<<		<*>	>>> Lower>>>		Difficult to answer
	Very high	High	Average	Slow	Very slow	
Scores	5	4	3	2	1	0

Comments (description):

1.4: Cultural landscape

Scale level	<<< Higher <<<		<*>	>>> Lower>>>		Difficult to answer
	Very high	High	Average	Slow	Very slow	
Scores	5	4	3	2	1	0

Comments (description):

FIG. 1: The beginning fragment of questionnaire

The decision-making process with experts' participation is supported by different methods, namely the well-known SWOT-analysis and the Analytic Hierarchy methods, experts' procedures, as well as marketing analysis, statistical and sociological researches. It may involve groups of people, and participants of social networks. In this case, the convergence (sustainability and purposiveness) of group decision making could be guaranteed by integrating:

- strategic analysis methods;
- human-machine interaction with explicit consideration of human thought activity;
- networked strategic conversation technology;
- cognitive programming;
- genetic algorithms on the cognitive models for invers problem solving;
- AI, Big Data analysis technology, knowledge engineering.

The following aspects have been taken into account: the self-organizing interactions; the strategic actors assembling support; expert communities and network expertise development; the modern collective intelligence technologies; evolutionary methods of decision-making coordination; orientation on the rationalized use of features of human thinking; the visualization, augmented and virtual reality systems; the information and analytical systems for special purposes implementation; comprehensive monitoring of a wide range of factors; the introduction of the Blockchain technology.

4. CULTURAL HERITAGE SUPPORT SYSTEM

For achieving the above defined objectives the special Project was initiated. It consists of ICT and AI framework and eco-system for supporting the development and implementation of innovative business and governance models. The above listed goals and factors define the follow circumstances that impacts on the Project development:

- An enabling context for the development and wide deployment of new technologies, techniques and expertise to enhance industrial competitiveness and economic growth;
- Integrated approaches from multidisciplinary expertise and strategies for the preservation and valorization of CH through its innovative governmental and business models suggestions on adaptive re-use, based on multisided and multi-stakeholder architecture that links citizens, private and public entities bi-directionally;
- The fostering of new investment and market opportunities for businesses in the adaptive re-use of CH assets, both tangible and intangible;
- Creating the opportunities for stimulating the growth and jobs by permeating the networks that can effectively reach small and medium businesses and start-ups;
- The proposition of paradigms in adaptive re-use that favors the public sector in implementing the reference strategies and models for innovation in the context of culturally and economically inclusive societies;
- Contribution to the strategies for the sustainability of actions under environmental, economic and societal aspects through apt weighting of sustainability parameters in every adaptive re-use model output.

The novelty in the Project's open framework is that it candidates to be an enduring technology transfer experiment for AI and e-expertise. It intends to establish a permanent link and technology transfer between utmost collective and AI researches' results and the society actors. The Project initiative conveys a multi-disciplinary set of experts into the complex problem of establishing a persistent and long-term innovation framework for the sustainable re-use of CH in different countries.

The most pressing challenge for the Project is to ensure the sustainable development through deeper control on circular economies and climate change. The key drivers implemented in the strategy that the Project more directly impacts are:

- the boosting of innovation management and governance CH skills and assets;
- the addressing of the research and societal innovation divide;
- the support for strong partnership within Member States.

The Project overarching goals aim to represent an important component of the socio economic development strategies of countries. The integrated approach of the Project is basing on openness and innovation. It is a possibility for stakeholders and researchers to exploit a technology breakthrough. The Project tries to remove the barriers for entrepreneurs to bring "ideas to market" and soon. Moreover, affordable faster setting of interoperable standards and responsible research are pursued in the Project's approach that chooses an open standard infrastructure and a bidirectional communication with all the market segments and potential stakeholders.

The AI and e-expertise over cloud technology are used to boost the quality and effectiveness of the activities concerning adaptive re-use initiatives. Most of the research activity will be focused in developing and validating the potential of AI-related technologies applied to electronic brainstorming to gets an evolutionary distributed decision making system.

The result of the project will be the above mentioned methodology and the multi-agent recommendation system (networked decision support system) that exploits "implicit culture" not just for generically searching information on the Internet, but specifically to get high-level emergency of Global best practices to the complex deal of innovation and maintenance in CH. It must constitute a boost and a breakthrough with respect to already existent "digital" and "virtual collaboration" initiatives.

Recommendation systems change the way websites communicate with their users. They identify recommendations autonomously for individual users based on past purchases, searches and, more generally, on other users' past

choices and experiences. Most recommender systems take of two basic approaches: either collaborative filtering or content-based filtering.

Collaborative filtering arrives at a recommendation that is based on a model of prior user behaviour. The model can be constructed solely from a single user's behaviour or - more effectively - also from the behaviour of other users who have similar traits. When it takes other users' behaviour into account, collaborative filtering uses group knowledge to form a recommendation based on like users.

AI is the weapon used to introduce a breakthrough and a boost in the initiatives where the adaptive re-use of natural and CH assets usually cannot find adequate return on investments for both the public and the private sector. AI should support, with possibly unforeseen ideas, decision makers in filling up the investment gap through new, possibly unexplored, innovative governance, financing and business models. It accelerates the networked authority, experts or citizens group decision-making processes, including strategic conversation, about re-using CH, by using modern collective and context artificial intelligent technologies.

5. THE PROJECT PLATFORM

The Project platform tries to reach, identify and to coordinate the added value information to let primarily public authorities to act on a secure ground for decisions on strategies and policies to enforce in the field of CH, in particular in the potentially underexploited context of adaptive re-use.

The policy-maker that adopts the Project's tools can rely on a different communities quality certified means for supporting the innovation actions and decisions. The risks in the wrong decision can then be ascribed to the tool itself, while the popularity of some possible good effects can be earned by the politician herself. The utility in such a kind of tool, as primarily perceived from the public official, is the possibility to act at low risk and with maximum reputation gain. As an externality effect, the bidirectional link with citizens and private entrepreneurs is activated and leveraged optimally while the actions generated on innovation provide positive effects on the whole society.

The research activity in the project is manifold: it encompasses "open data models and knowledge extraction", "machine learning", "collective intelligence", "recommendation systems", "CH adaptive re-use", "innovation business models" and "case-based reasoning".

5.1 Platform's activity modules

In Fig. 2 the fundamental scheme of the activity modules is depicted. Three major modules compose the Project platform. The first is the *Citizens desk*. This module provides a bidirectional information connection to citizens. People can access and subscribe to it to receive relevant and timely information about major initiatives in the CH sector in Europe and in particular in their Region or residence area. On the reverse direction, citizens can provide data and information to the platform about needs and ideas or request specific information and help.

The second module is for private entrepreneurs. These actors can subscribe to use the *Innovation wizard*. This tool will constitute a complete help desk and guided procedures to the easy and fast track to innovation. It will provide templates, forms and consulting for encouraging the participation of companies to the innovation initiatives and funding tenders. The entrepreneurs, in particular not structured start-ups, can receive suggestions and forecasts for the risks and expected return along with a draft business plan for the initiative they are interested in. This process requires first that entrepreneurs register and provide the correct amount of information into the platform. This information in input feeds the platform itself to grow, improve, and offer more specific and effective services.

The third, and probably the most challenging and innovative module is the *Strategy deputy*. It is conceived mainly as an assistant for the politician or the public officer. This module will help to accelerate networked strategic conversation with getting consensus during group strategic decision-making. It will provide suggestions, forecasts, best practices to follow and permanent link to major strategic funding initiatives in Europe for CH. The assistant will suggest good initiatives to pursue in the officer's intervention area, while assessing the risks and returns of the action. Moreover, in this module they can find templates for the tenders, for the decree, and for the communication of actions. In return, the platform will receive information about the intentions, ideas and trends of local initiatives that can be used to develop and suggest new needs and strategies at the European level.

Fig. 2 expresses graphically the number and the functional importance of the links that are created with major foreseen stakeholders and users of the Project platform. The link round element denotes the circularity of the elements transferred forth and back between the platform and the actors.

There are four main categories:

- *Services*: Service actions that are implemented during transactions. A service is provided by the platform facilities, it can be requested as well from the platform to the actor;
- *Knowledge*: Actor receives knowledge and supplies his own to the platform. These processes could be supported by knowledge management technology;
- *Value*: Depending on the nature of the actor, the platform provides value of material or immaterial nature (monetary, participation, funding opportunities, jobs etc.) and receives back from the actor (funding, subscription or pay-per-use-fees, reputation, publicity, improvement etc.);
- *Information*: Wealth of data but also organization and procedures are transferred in both directions.

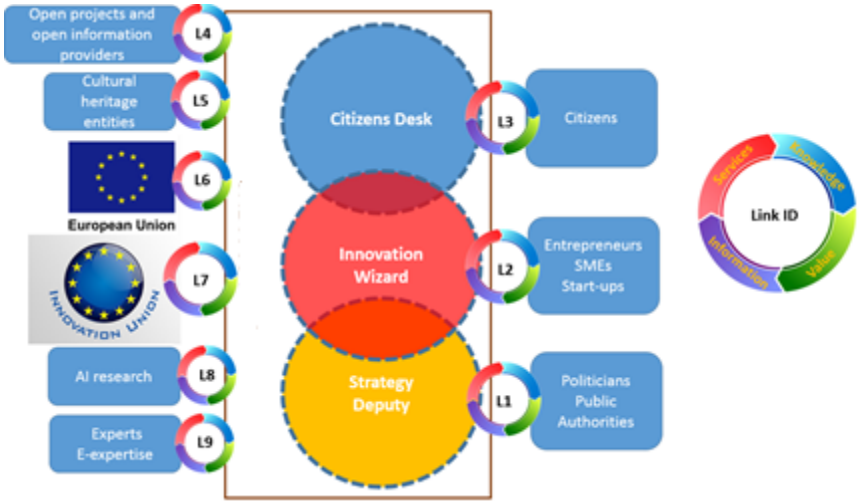

FIG. 2: The Project concept.

Each Link is associated to an identifier that will be used in this proposal to detail its nature, its impact, the innovation potential, and the specific dissemination and communication actions and exploitation.

5.2 The platform's cyber-physical loop and technologies

The ICT and AI Project's platform is realized as an active knowledge-processing platform, a Knowledge Management System (KMS) that goes beyond typical Content Management Systems (CMSs in Web 2.0 technology). The platform will have a modular architecture, with the aim to receive and host contribution from researchers in the long term by providing them with plenty of data and information to test and train their solutions in the cultural heritage context. The platform will also adhere to the cyber-physical systems' paradigm as it is designed to create a loop between the edge, where the physical world and people react and communicate, and the digital information processing performed in the cloud.

The interface from/to external sources and/or open platforms will be compliant with the FIWARE API definition (www.fiware.org), thus ensuring a wide integration with all projects and resources based on such a European standard. Moreover, being the platform concept and architecture reusable in other contexts by simply refilling with new information and knowledge, the potential of the work here foreseen is huge for the long term. It essentially remains as an adaptive infrastructure able to inject the boost of AI for the solution of many innovation strategies and implementations by providing means for optimal production of innovative and sustainable business and governance plans.

In Fig. 3 we show the work flow and at the same time the continuous cyber loop of the activities performed. This workflow is iterated three times during the initial training phase and its final refined and stable version will constitute the production mechanisms at the end of the research phase. In the figure are also evidenced the clusters of the activities that will be described in their methodology in the following of the section, namely: adaptive re-use and preventive maintenance; questionnaires; Business Model Techniques (BMT); open data models and

archives; recommendation systems; case-based reasoning; benchmarking; gender weighted approach; demonstration and piloting.

Traditional approaches regarding conservation of cultural heritage sites (development of restoration works with a weak and unsustainable use or without a previous management strategy for the future) must be overtaken in order to develop innovative strategies focused on their re-use and preventive maintenance based on creative and sustainable ways of providing an enriching role for cultural heritage sites.

A successful strategy for the adaptive re-use of cultural heritage must be based in two key points: first, a deep knowledge of the already developed initiatives within this field, and second, an efficient scalability and replicability system. The platform project will face both of them in order to provide successful and efficient results. It will be analysed the state-of-the-art regarding the European initiatives related to any kind of re-use of cultural heritage elements and to extract the key aspects that are beyond them. Not many studies have been developed by the moment, although some economic analyses have been published (Alonso and Martin, 2008), (Alonso and Martin, 2013). This work will go beyond the economic data, following a holistic approach to incorporate other sources of information and to take in consideration also social, political, legal and technological issues. The costs and benefits of preventive maintenance of historical buildings will be deeply analysed in order to compare such management approach with the traditional conservation activities that are usually developed once that the damage has occurred. Platform will be focused on acquiring data about costs of most of the usual big scale restoration actions in buildings (such as roofs and wall restorations), in order to compare them with small scale but continuous preventive actions (vegetation cleaning, gutter cleaning, little pieces replacement, etc.). They will allow us to define strategic guidelines for a preventive maintenance and to justify them with the economic benefit that they will provide. The main conclusions of such research will set the basic inputs for the Decision Support System's tools. The variables and criteria obtained are used in order to provide strategic planning and re-use guidelines in a general frame of European cases.

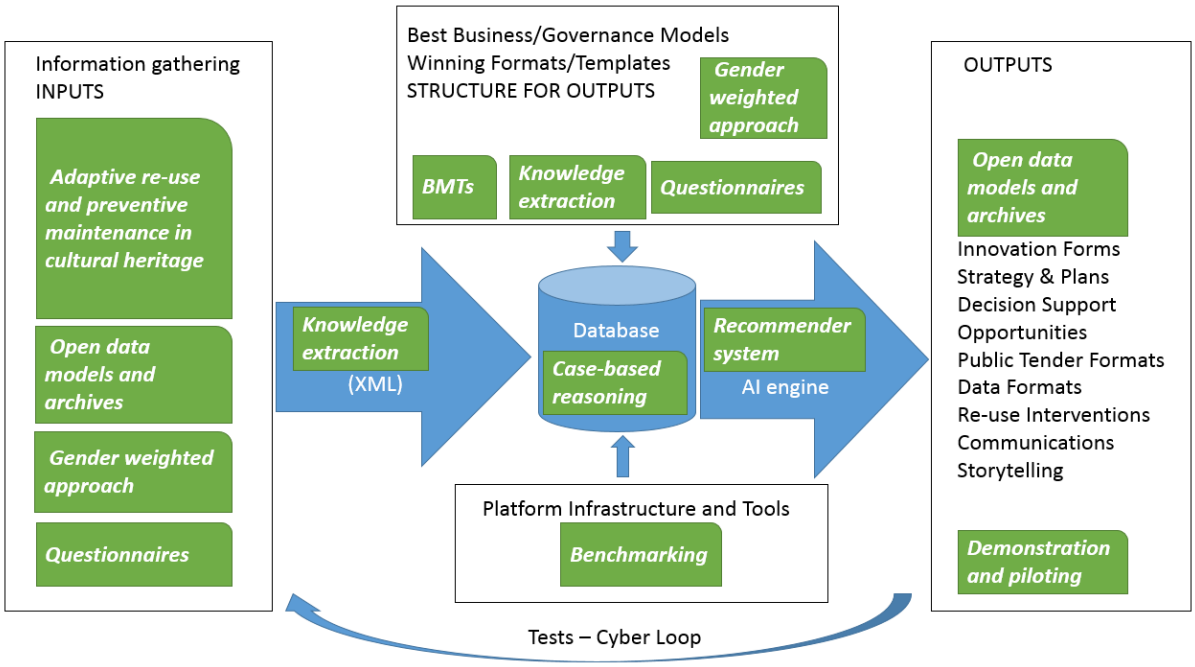

FIG. 3: The platform's workflow and cyber-loop.

The previous activity will be in close link to the development of innovation and business models as output from the platform and will enable research for the mapping of winning business models, their expression into a canonical set of components, categories or best practises to be used. This will constitute mainly the grounding components for the recipes output from the tool. Business model techniques (BMTs) are tools which can be used in a business design process of a company (most effective for SMEs), aiming at the creation of strategies, reasoning, insights and improvements. These are the major and baseline tools for the achievement of the parametrized models used to provide a contextual semantic structure that is used to produce the recommendation outputs. The research action

will extend the methodology beyond the private business context to the models of governance for innovation in the field of adaptive re-use of cultural heritage.

All the users groups involved in the testing phase will be required to fulfil a questionnaire on the quality of the outputs. The best form of the questionnaire will depend on the definitive semantic structure of the output information. For the inputs, a structure of a possible questionnaire that guides information extraction both from archives than for human experts. The requests would be mainly answered from humans by selecting items from a multi-choice list, so that the answers can be codified. One or more item can be selected in a single answer. Some other request must be answered with a free text (description). There will be a complementary input text box for including user's comments about each category. A final request will be open to include general comments, synergies and opportunities. The same categories will be extracted in case of automated archive information extraction.

Recent studies in multi-agent systems, though applied to a different field, allow to design a metric for the capabilities and necessities of actors involved in a collaborative tasks (Wassermann and Fay, 2017). In our case the same methodology is mutuated and adapted to express and measure the essential set of key performance indicators (KPIs) that guides the cyber-loop towards its optimal performance.

Although questionnaires are a traditional and rather effective means for information and knowledge acquisition, platform will push further to include in the process some recent ICT-based augmented methods. To the plain text, more contextual and meta-information can be added that enriches and extract the deeper or hidden meanings of the text and the answers. In this view, the word *questionnaire* is a mere naming convention that is extended to intend and encompass a richer bunch of information and insight (when available): a simulation and training agent would be mostly undistinguishable from a human agent from the behaviour (in the sense of query answering).

The platform will implement the extraction of knowledge from semi-structured sources (legal documents, questionnaires, public regulations, etc.) and its processing. The result of this activity, based on machine-learning techniques, is a categorization of the experiences made for the sustainable re-use of cultural heritage, which defines a set of best practices to apply in well-defined contexts. The only way to obtain this result is the definition of the correct knowledge representation model of the past experience and of the application domain (from the e-expertise). This can be done by using domain ontologies, as a basic tool of a generalization mechanisms able to extract new knowledge from the acquired one. The results of these processes (models for knowledge representation and knowledge instances) will be made available to external applications and platforms as Open Data. The data representation standards and access procedure will be defined to be compliant with the guidelines established in the Horizon 2020 Open Research Data Pilot.

The openness is also guaranteed by the adherence to the FIWARE standards. Indeed, FIWARE is a perfect tool and paradigm for the Project's platform as its mission is: "to build an open sustainable ecosystem around public, royalty-free and implementation-driven software platform standards that will ease the development of new Smart Applications in multiple sectors". The FIWARE platform provides a rather simple yet powerful set of APIs (Application Programming Interfaces) that ease the development of Smart Applications in multiple sectors. The specifications of these APIs are public and royalty-free and with publicly available open source reference implementation of each of the FIWARE components. The FIWARE Catalogue includes links to other catalogues bringing information about domain-specific enablers (DSEs) to be combined with those serving general purposes (Generic Enablers - GE). They will be used to create the infrastructure of the components, tools and interfaces of the platform.

The AI modules to be developed are plug-ins components in the FIWARE framework technology, while the most important and invariant part is the prior knowledge provided through the collective work and e-expertise. All the AI modules developed by WP1 have to implement a cumulative learning process which uses prior knowledge, stocks it and adds to old reach a new state of knowledge. A typical scheme of this kind of learning is provided in Fig. 4.

The above expresses the behaviour of an autonomous learning agent that uses background knowledge which has to be obtained in the first place, in order for it to be used in the new learning episodes. The agent's life history will therefore be characterized by cumulative or incremental development. Once the agent has acquired and processed the knowledge the new speculations become less naïve and the learning grows more effectively.

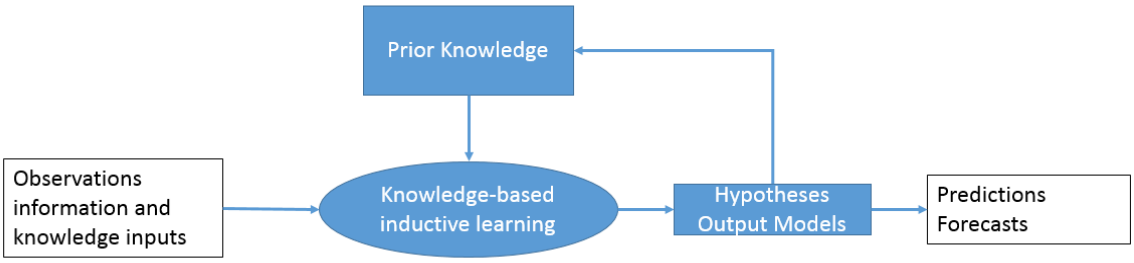

FIG. 4: Cumulative learning process

Means to obtain the learning scheme in Fig. 4 can come in different flavours by:

- Explanation-based Learning (EBL)
- Relevance-based Learning (RBL)
- Knowledge-based Inductive Learning (KBIL) through Inductive logic programming (ILP)

The last of the methods is the dominant methodology and it will be the first choice for the AI core module (1st AI solution). Moreover, it is well known that inductive learning can be performed as an inverse deduction. This creates an association with case-based reasoning.

Case-based reasoning has been used in many fields with success (e.g. in medical diagnoses machines, or Travel Advisory System systems as TripMatcher, ITR Intelligent Traveller Recommender) and it is part of Knowledge-Based Recommender Systems (Aggrawal, 2016).

The first AI solution tempted will be based on this well-known and tested technology. It will provide a secure bay that assures the reaching of minimal objectives for the project. It has be proven that a consistent learning can be easily obtained from such systems that capture experts' way of thinking by relying on still simple Euclidean norms. For a second AI solution, it will be introduced probabilistic models and statistical inference with Bayesian approaches (Rasmussen and Williams, 2006), (Vanhatalo et al.,2013). This will provide a boost in the learning rate whilst keeping consistency in the solution. Moreover, reinforcement learning approaches will be introduced. Reinforcement learning has been successfully applied to robotics and games in the last decade. It will bring ground-breaking pushes to the policies decisions in cultural heritage strategies and innovation, where decision making and planning with partial state information is a core problem. The policy, in technical terms, is a function that maps states to actions. In this context, the primary interest is in parameterized representations of the policy that have fewer parameters than there are states in the state space. The model parameters will be set from the activity pertaining to winning business plans and strategies to innovation. The minimum objective is that the outputs comply with EU innovation state-of-the-art schemes, or possibly suggest new ways beyond the state of the art. To train the system, multiple scenarios will be simulated or existent cases data will be generated to produce a correlated sampling methodology (Ng and Jordan, 2000), (Billard et al., 2016).

The quality and the strength of the solutions developed will be challenged and benchmarked with state-of-the-art tools for collective expert decision and consensus meeting, which are currently available from the authors' previous work. The benchmark will be obtained by purchasing it as a service. The benchmark test, beyond rating the AI solutions, will also challenge and demonstrate the openness of the architecture and its capability to include third party software components.

The Project framework is concerned with gender and age (non-discriminatory in general) aspects by design. Beyond the not enough absence of bias toward gender preferences or orientation it will actively incorporate gender themes in the weightings for decision and models output by providing knowledge and information that constitute input constraints for the decision support. Any statistical data and knowledge collection will seek to provide sex-disaggregated analysis to allow the identification of gender differences and gender inequalities. Possible gender differences usually appear in the burdens of administrative practices, which may be significantly different between women and men, and the policies that may have significantly different impacts between men and women. The tools in output will include the apt corrective actions.

6. CULTURAL HERITAGE MACHINE LEARNING

Many commercial packages are available for learning machines based on decision trees, ensemble boosted neural networks and others, but having a huge number of training data makes more difference in performance than the choice of the technique or tool. Most of the engineering problem is deciding what data and where to find them and in which form. It is confirmed also by the success of the widespread commercial Big Data applications run by Google or Amazon. It gives a first lesson to the Project not to expect an ultimate algorithm for machine learning but focus on the availability and well format of data. Considering that decision models contain many qualitative factors, for the machine learning on the base of the Big Data analysis it is necessary to use methods of cognitive modelling (Raikov et al., 2016).

The Project has to mimic and semantically interpret the more complex behaviour of an expert. This is expressed by Fig. 5.

FIG. 5: The Project expertise

In that regards, the Project implements a form of Collective Intelligence (CI) in that it helps both shared and group intelligence to emerge from collaboration, collective efforts and even competition of many individuals, finally favouring consensus decision making. This will emerge from the synergies among:

- Prior CH data-information-knowledge;
- AI multi-agent software systems, including electronic brainstorming, virtual collaborating, cognitive modelling, genetic algorithm, networked group decision-making;
- Human experts (those with new insights as well as recognized authorities) continually learning from feedbacks to produce just-in-time knowledge for better decisions (than these three elements acting alone).

The Project is intended to cover a TRL 5 (International measure of Technology readiness levels: Component and/or breadboard validation in relevant environment) and to position itself in the spectrum from 'lab to market'. It is going to prepare the ground by providing high quality and open infrastructure that will be a ground for subsequent innovation actions to make the steps to TRL 9 (Actual system proven through successful mission operations).

The first activity will test and train the instruments whilst establishing an enduring context for follow-ups searched through the dissemination and exploitation activities. A web-based platform and apt user interfaces aimed providing access to the fundamental services for citizens, private entities and policy makers, who may enjoy the effectiveness of the contents, formats and the decision support system foreseen. The platform will be also the major means for requiring direct consultancy to the project expertise among different partners and collaborations. With its experiments and demonstration on case studies, it will provide an experimental instance of innovation paradigm and its initial dissemination to specific primary and secondary targets for adoption, standardization and exploitation.

The Project framework is embedded in active research on the field of strategic decisions in CH related initiatives. Its research group has been carefully designed to enforce the multisided connection through the ICT platform concept. To enable the AI experiment, and to effectively taking care of cross-cutting Social Sciences and Humanities dimension and aspects, a minimum set of multidisciplinary stakeholders have been summoned by merging: ICT, AI and CH experts research groups; advanced research on innovative business and governance model structures and methodologies and tools based on ICT and AI for the enhanced user's needs acceptance; responsible research and innovation management, new business models implementation; respectively representing complementary of entities with expertise advice and links to superintendence entities, local tourism, communities of CH, adaptive re-use funding management, and etc.

6.1 Application of Machine learning approach in case studies

The CH enhancement is boosted by actions aimed to large communities and by the effective use of the cultural values. It is noticed a progressive increase in availability and sustainability of ways for citizens to exercise their right to information about and enjoyment of the cultural heritage. The present paper shows various methods based on digital mediation techniques: such as data platforms, simulations, virtual tours or 360° pictures and videos, 3D reconstructions, user-friendly interfaces, participatory and immersive learning, renewed usability of network navigation tools, and, more in general, multimedia/multi-modal means of accessing information, have redefined space and time in both the dissemination and use of knowledge (Brusaporci, 2015).

The first case study, in the present paper, is the "Flaminia Nextone" project: it aims to validate an easy way to make affordable, sustainable and economically productive the protection and the exploitation of the archaeological heritage and landscape. Main revenue of the project, which is in its concluding phases, is to enlarge the knowledge, appreciation and exploitation of Via Flaminia cultural historical sites, starting from existing databases. The data are managed in a cloud storage that encourages public-private partnerships for heritage digitisation. Data storage and content protocol ensure the interoperability matching already defined standards (Europeana), as well as recommended in the Digital Agenda for the digitisation of cultural material and its preservation on line (Clini et al., 2015). Several drawings and surveys are reused to build a whole intangible heritage about Flaminia area and to reinforce cultural identity through a widespread (outdoor & indoor) museum.

Another case study is related to an innovative management of an historical building, the Santa Maria cathedral in Vitoria-Gasteiz (Spain). This medieval construction represents an important milestone thanks to the creative approach based on the concept "open for restoration works". Contrarily to what usually happens when a building is being restored (it get closed for public visits), the technical team decided just to do the opposite, so that visitors can see the building during its restoration and thus discovering a new perspective of the cathedral. This initiative has attracted many people and has definitely helped to economically and socially improve Vitoria's medieval quartier. Such an extraordinarily new sense of returning to the society the economical investment made by public bodies was awarded with a Europa Nostra Prize in 2002. Thanks to this case study, a wide experience related to the sustainable management of a historical building has provided practical information and data for the Machine Learning stage of the Project. In particular, it has been possible to put in contrast the derived costs of the restoration works with the socioeconomic return of such activity in the historical quartier of Vitoria-Gasteiz by means of the cultural visits to this building and the boost of other economic activities in relationship with cultural tourism.

Finally, the last case study is the Salt Valley of Añana (Spain). It is a unique industrial salt landscape that consists of thousands of platforms or salt pans, springs, channels, wells and storage facilities. The Añana salt works is one of the oldest salt production facilities in the world. "White gold" has been produced here uninterruptedly for 6,500 years. Salt Valley is an example of good heritage conservation & use practices that seamlessly combine the management and enhancement of all its attributes, including the industrial use of salt production and commercialization. This case study has provided quite interesting and useful data of the economical return obtained from the reuse of an abandoned historical industrial site. In particular, the production and commercialization of salt has been a key point for the sustainable recovering of this site, and such information has been used for the Project's Machine Learning.

The resources and methods performed on the above mentioned case studies will now be used on the base of Cyber physical intelligence (Fig. 6).

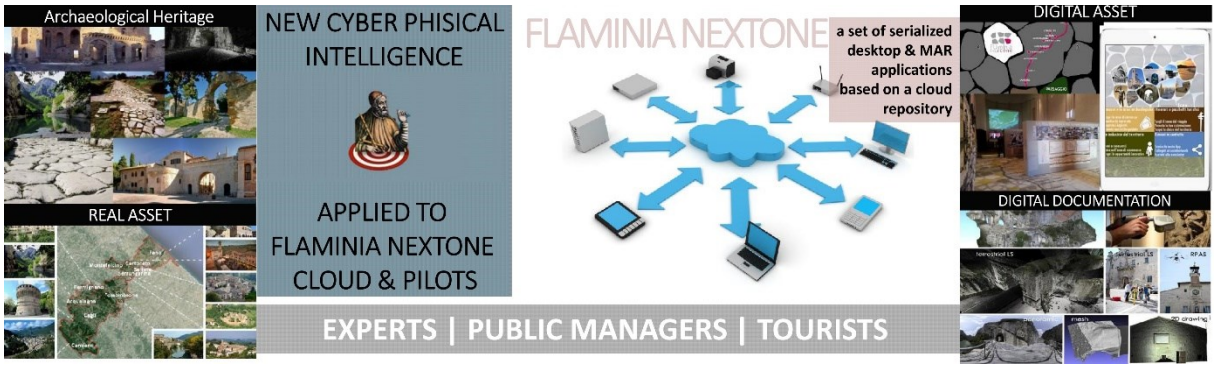

FIG. 6: The Project Flaminia Nextone kind of data available for the new Cyber physical intelligence

7. CONCLUSIONS

Traditional approaches regarding conservation of CH sites (development of restoration works with a weak and unsustainable use or without a previous management strategy for the future) must be overtaken in order to develop innovative strategies focused on their re-use and preventive maintenance based on creative and sustainable ways of providing an enriching role for CH sites.

A successful strategy for the adaptive re-use of CH must be based on two key points: first, a deep knowledge of the already developed initiatives within this field; and second, an efficient scalability and replicability system. The special Project is initiated that faces both of them. The main objectives of the system are therefore to analyses the state-of-the-art regarding the countries' initiatives related to any kind of re-use of CH elements and to extract the key aspects that are beyond them. Not many studies have been developed by the moment, although some economic analyses have been published. This work is going beyond the economic data, following a holistic approach to incorporate other sources of information and to take in consideration also social, political, legal and technological issues.

The project also involves several modern AI tools and recognized experts in the CH field through the external advisory board. The initial data searches are complemented with several workshops in which such experts within the frame of CH management participate in the processes in order to share their knowledge and to discuss about the strengths and weaknesses of each case. The key points for a successful scalability and replicability of such initiatives will be finally analysed through a common and enriching discussion.

ACKNOWLEDGMENTS

The project presented in the paper is an internal project partially funded by authors' institutions and conceived as a follow-up of previous projects. The authors want to mention Flaminia Nextone project – Cultural Evolved District of Marche region (POR_FESR founding) and two Academic Strategic project (PSA) founded by Polytechnic University of Marche: CIVITAS (ChaIn for excellence of reflectiVe Societies to exploit dIgital culTural heritAge and museumS. A pilot case in Palazzo Ducale at Urbino); "Re-thinking digital buildings according to the cyber-physical paradigm: modelling and development".

Besides, the authors want to thank the collaboration of Santa Maria Cathedral Foundation (https://www.catedralvitoria.eus/en/home/) and The Valle Salado de Añana Foundation (http://www.vallesalado.com/pagina.php?id_p=130&i=eng), who have kindly allowed the inclusion of such cultural sites as case studies for the project. We would like also to thank the archaeologist Dr. Alessandro Biagioni for his collaboration and the proposition of PTOLEMAEUS as the project's name.

REFERENCES

Aggarwal, C. C. (2016). Knowledge-Based Recommender Systems. In *Recommender Systems*, Springer, Cham, 167-197.

Alonso, J., and Martin, J. (2008). Conservación del patrimonio histórico en España*, Análisis económico (Conservation of cultural heritage in Spain. Economic analysis*). Fundación Caja Madrid. Madrid. 2008.

Alonso, J., and Martin, J. (2013). Activos culturales y desarrollo sostenible: la importancia económica del Patrimonio Cultural (Cultural assets and sustainable development: the economic importance of Cultural Heritage), *Política y Sociedad*, Vol. 50, No. 3, 1133-1148.

Ball, R. (1999). Developers, regeneration and sustainability issues in the reuse of vacant industrial buildings. *Building Research & Information*, Vol. 27, No. 3, 140-148.

Billard, A., Calinon, S. and Dillmann, R. (2016). Learning from humans, *Springer Handbook of Robotics*, Springer International Publishing, 1995-2014.

Brusaporci, S. (2015). On Visual Computing for Architectural Heritage, *Handbook of Research on Emerging Digital Tools for Architectural Surveying, Modeling, and Representation* (Brusaporci S., editor), Hershey, PA: IGI Global , 94-123.

Clini, P., Quattrini, R., Frontoni, E. and Nespeca, R. (2015). A New Cloud Library for Integrated Surveys: The Ancient Via Flaminia and the Nextone Project, *Handbook of Research on Emerging Digital Tools for Architectural Surveying, Modeling, and Representation*, IGI Global., 579-606.

Crane, R. and Landis, J. (2010). Planning for climate change: assessing progress and challenges, *Journal of the American Planning Association*, Vol. 76, No. 4, 389-401.

DEH, Department of Environment and Heritage (2004). Adaptive reuse: Preserving our past, building our future, *ACT: Department of Environment and Heritage,* Commonwealth of Australia.

Douglas, J. (2006). *Building adaptation*, Routledge.

Gubanov, D., Korgin, N., Novikov, D. and Raikov, A. (2014). *E-expertise: modern collective intelligence*, Springer International Publishing

Jagarajan, R., Asmoni, M. N. A. M., Mohammed, A. H., Jaafar, M. N., Mei, J. L. Y. and Baba, M. (2017). Green retrofitting–A review of current status, implementations and challenges, *Renewable and Sustainable Energy Reviews*, Vol. 67, 1360-1368.

Markham, A., Osipova, E., Lafrenz Samuels, K. and Caldas, A. (2016). *World Heritage and tourism in a changing climate*, *UNESCO Publishing.*

Ng, A. Y., and Jordan M. (2000). PEGASUS: A policy search method for large MDPs and POMDPs, *Proceedings of the Sixteenth conference on Uncertainty in artificial intelligence*, Morgan Kaufmann Publishers Inc., 406-415.

Raikov, A. N. and Panfilov, S. A. (2013). Convergent Decision Support System with Genetic Algorithms and Cognitive Simulation, *IFAC Proceedings Volumes*, Vol. 46, No. 9, 1108-1113.

Raikov, A. N. (2015). Convergent networked decision-making using group insights, *Complex & Intelligent Systems*, Vol. 1, No. 1, 57-68.

Raikov, A. N. (2016). Organizational Structure Optimization with the Questions-Criteria Hierarchy, *IFAC-PapersOnLine*, Vol. 49, No. 12, 1532-1537

Raikov, A. N., Avdeeva, Z. and Ermakov, A. (2016). Big Data Refining on the Base of Cognitive Modeling, *IFAC-PapersOnLine*, Vol 49, No. 32, 147-152.

Rajčić, V., Skender, A. and Damjanović, D. (2018). An innovative methodology of assessing the climate change impact on cultural heritage, *International Journal of Architectural Heritage*, Vol. 12, No. 1, pp. 21-35.

Rasmussen, C.E. and Williams, C.K. (2006). *Gaussian processes for machine learning (Vol. 1)*, Cambridge: MIT press.

Rypkema, D. and Cheong, C. (2011). Measurements and indicators of heritage as development, *ICOMOS*, 755-762

Rypkema, D., Cheong, C. and Mason, R. (2011). Measuring economic impacts of historic preservation, *Advisory Council on Historic Preservation*.

Vanhatalo, J., Riihimäki, J., Hartikainen, J., Jylänki, P., Tolvanen, V. and Vehtari, A. (2013). GPstuff: Bayesian modeling with Gaussian processes, *Journal of Machine Learning Research*, Vol. 14, 1175-1179.

ViMM (2018) *The ViMM Manifesto for Digital Cultural Heritage*. Accessed October 2018: *https://www.vimm.eu/wp-content/uploads/2018/09/ViMM-Manifesto-for-digital-culture-heritage.pd*f

Wassermann, E. and Fay, A. (2017). Interoperability rules for heterogeneous Multi-Agent Systems: Levels of conceptual interoperability model applied for multi-agent systems, *Proceeding of the IEEE 14th International Conference on Industrial Informatics INDIN 2017*, 89-95.

Yung, E. H. and Chan, E. H. (2012). Implementation challenges to the adaptive reuse of heritage buildings: Towards the goals of sustainable, low carbon cities, *Habitat International*, Vol. 36, No. 3, 352-361.