STORM integrated solution: a toolkit of collaborative and decision-making services and tools

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Abstract. The current world is increasingly supported by a knowledge-based economy, where technological, economic, political, social and cultural changes modify the nature of human relationships. The Information and Communication Technologies (ICTs) revolution along with the spread of different and faster channels have become important driver to disseminate knowledge and information. In this changing landscape, knowledge is considered one of the most valuable assets able to generate growth and competitive advantage. Knowledge sharing plays a central role specifically during emergency, allowing the access to and the availability of critical information regarding risks and disasters. Lack of information complicates the efficient management of catastrophes and weakens the decision-making processes. For these reasons, it is fundamental to develop an infrastructure able to manage knowledge and, most specifically, to increase economic and social values fostering knowledge creation and sharing, to use innovation to perform better, to be updated and to enhance sustainability. In such complex situations, the STORM project aims at building a collaborative and dynamic environment allowing the actors to interact with each other and to join their efforts towards highest levels of cooperation and coordinated decision making approaches. Making fast and efficient decisions requires supporting tools allowing a prompt situational picture and critical information sharing based on effective use and coordination of resources, people, and information, where information and knowledge are distributed. In the context of the STORM project, the proposed tools and services enabled by IT technologies enhance collaboration, co-ordination and to support decision making amongst stakeholders, providing, at any moment, a clear situational picture. Existing knowledge (e.g. best practice, guidelines, lessons learned, procedures and processes, etc.) related to natural disaster risks and impacts can help teams of experts in making decisions and sharing new knowledge (e.g. from the situational picture, risk assessment and data analytics) for a prompt and more effective recovery. As a main benefit, the involved actors will be aware about the formulation and selection of risk reduction measures based on available risk information and stakeholders’ needs, speeding up response time where the right people with the relevant skills and disaster events are identified in a more timely manner.

1. The importance of collaboration and knowledge sharing during disasters

Knowledge sharing plays a central role during emergency, allowing the access to and the availability of critical information regarding risks and disasters. The lack of effective knowledge sharing practices during crisis can be identified as one of major reasons behind the unsatisfactory performance levels of...
current disaster management activities. The lack of a continuous and efficient coordination among all the stakeholders involved in preserving and securing the cultural heritage assets is one of the main concerns raised during crisis. All these highlight the importance of embracing knowledge management within the context of disaster management.

Crisis response management is a collaborative activity which requires a highly cooperation among all the involved actors with the aim to face and recover from the risks of crisis and disaster events. It should be a critical need to gather and access critical real-time information and share knowledge resources to make faster and more informed decisions [1]. Lack of up to date information threatens the efficient management of catastrophes and makes the decision-making process a very difficult task [2].

Communication and decision-making during disaster must occur in a compressed timeline since faster response than usual is needed to stabilise a dangerous situation, prevent further losses, and begin reconstruction. In such complex situations, a collaborative and dynamic environment allows the actors to interact with each other and join their efforts so as to collectively cooperate. Such a kind of environment needs supporting tools allowing a timely situational picture generation and sharing. In this way, the communication and collaboration among users is facilitated, as well as the efficiency and effectiveness of decision-making is improved.

For this reason, in the context of the H2020 STORM (700191) research project, a collaborative and decision-making platform was designed and implemented. At any moment, the end users can have an up to date situational picture to better act either in the prevention phase to mitigate the effect of climate phenomena or in the intervention phase when a disaster occurs. The proposed tools vectored through leading-edge technologies are expected to enhance collaboration, co-ordination and to support decision-making amongst stakeholders. This will be a resultant of having faster access to information and knowledge, that is crucial for collaborative performances by speeding up response times. Moreover, the right people with the relevant skills are identified more quickly and disaster events dealt with in a faster manner.

The rest of the paper is organized as follows: in section 2, the STORM Collaborative and Decision-Making platform is introduced and its collaborative and operative services are presented in subsection 2.1 and 2.2, respectively; in section 3, the experimentations carried out at the STORM pilot sites are described; in section 4, the exploitation of STORM results is outlined; finally, in section 5 conclusions are drawn.

2. STORM Collaborative and Decision-Making platform

There is an urgent need for a knowledge sharing platform that promotes an engagement between all the stakeholders of the Cultural Heritage domain, for a more extensive and regular communication, before, during and after a disaster.

As a result, in STORM, an integrated solution, namely STORM Collaborative Decision-Making platform, has been proposed where collaborative and operational environments are strongly interconnected each other. The platform aims to be the enabler (and at the same time supportive) tool for the development of a collaborative environment. A customizable dashboard, mapping the current situation in a synthetic way and gathering the most relevant information, is a key asset for supporting an efficient and effective decision making.

The STORM Collaborative Decision-Making platform provides a set of specific collaborative and operative services coming from the two interconnected environments. Specifically, the collaborative services are on the top of the dashboard, namely Network & Site, Process Mining, Update News and Document Library, along with the User Profile and the Semantic Search. The operative services are on the left side, namely Sensory Map, Visual Analytics, Event Manager, Risk Assessment and Situation Awareness [3][4]. As an example, Figure 1 shows two operative services, Situation Awareness and Sensory Map (then described in sec. 2.2.1. and 2.2.5.)
2.1. **Collaborative services**

The basic principle of a collaborative work is the concept of a working group, a set of individuals interacting with each other with some regularity. They are dependent on each other and share the same goals and tasks and each one has a specific and recognised role, based on the circularity of communication. As a result, a **Collaborative Working Environment (CWE)** provides a set of services that encourage, capture, organise free and open interaction among actors to create and exploit the collective knowledge. Specifically, a set of **collaborative services** is provided in order to enable the Cultural Heritage and emergency stakeholders to collect, contribute and share data and information as well as the knowledge on the potential threats, vulnerabilities, risks. These services allow also to share data about the actions to be performed to manage, in a suitable way, the critical situation when it occurs, putting in the loop both their own experience and skills. The available data and information related to the disaster (i.e. threats, vulnerability and risks) and how have to be managed, are collected, managed and shared among different community of stakeholders (e.g. emergency operators, first responders, citizens, public authorities, etc.).

This allows users to establish a virtuous mechanism of using, elaborating and releasing new knowledge that becomes a valuable asset during the decision-making processes. One of the objectives of the STORM platform is to support users in carrying out part of their daily activities and their work. The specific collaborative services featured in the CWE are describe in the following subsubsections.

2.1.1. **User Profile.** Every user registered on the platform has its own profile and role and access to a set of specific sites he belongs to. **User profile** gives each user a complete visibility into how other users manage knowledge and their activities. Moreover, it shows users’ relevant roles and responsibilities, so each user knows who is responsible for each relevant area, procedure and task.

2.1.2. **Semantic Search.** The **Semantic Search** service is a functionality featured as an intelligent information retrieval. This approach tries to understand the intent and the context around a query in order to retrieve the most pertinent resources, related to the particular information requested. It delivers the user a better match to queried content and information.

2.1.3. **Network & Sites.** The **Network & Sites** is a way to organise activities among all the members belonging to the same site. In this way, it is possible to avoid sharing of data, activities with unwanted receivers.

2.1.4. **Process Mining.** The **Process Mining** supports site managers and Cultural Heritage professionals during the STORM Quick Assessment process, covering both the phases of feeding and using the system, before and after a hazard. The STORM Quick Assessment process consists of the following procedural phases: Data Collection, Preparedness, Response and Debriefing. Particularly:
1. **Data Collection** - this first phase takes place before the hazard happening and, at this stage, the process involves a feeding activity where the system is fed with all the relevant data and information. This allows to build a database containing the detailed multimedia knowledge concerning the site of interest, such as historical and technical data, material details at three different levels: site, area and item. In STORM, this activity is done using the description forms available on the platform through the Process Mining service.

2. **Preparedness** - this second phase has been identified with the aim to plan actions and resources in order “to be prepared” prior to the emergency, simulating a virtual hazard occurrence. In STORM, the preparedness forms give all the information required to be ready to face future real hazards.

3. **Response (First Aid)** - this phase takes place immediately after the occurrence of an emergency. The First Aid corresponds to practical actions made by trained personnel, with specific skills based on an intervention scheme identified during the Preparedness. When the real hazard happens, the service supports users to update the information added during the simulation phase (in the preparedness forms) in order to give better guidelines. A specific section of the item preparedness form is dedicated to the First Aid, namely section Planned Response (First Aid).

4. **Debriefing** – in this final phase, the assessment and the evaluation of what have been done during the emergency takes place.

2.1.5. **Update News**. This service allows users to share particular news. In this way, tacit knowledge on strategic issues arises. The service allows community users to add blogs, categorise and associate them to other contents on the platform.

2.1.6. **Document Library**. The Document Library is a service that supports document management (upload, view and download documents) among users. Each user can organise documents by grouping them into specific folders so that everyone can easily consult them. The service allows users to add a new folder in order to upload one or more documents at one time. [4]

2.2. **Operative services**

The Operational Working Environment (OWE) provides some operative tools, services and application for a collaborative decision making. The OWE development is not aimed at substituting the decision makers’ responsibilities, but rather to assist in making decisions by providing additional supportive tools and services to enhance understanding and management of a critical situation. General information (e.g. guidelines, reports, etc.) related to dramatic events, such as flood and earthquake, are made available, shared and dynamically adapted in near real-time by an ad-hoc team of experts, to identify the most urgent actions called for by the unforeseen emergency.

The OWE provides a quick view of the main parameters coming out from a systematic analysis and assessment of data and facts according to the users’ interests and needs. Stakeholders need to make informed and consensual decisions working together, sharing information and the best available data. A set of operative tools, services and applications helps to:

- generate the current situation to be analysed giving all the necessary information to identify decisions that need to be made;
- recognise the right processes/tasks to be selected and people (and their specific role) to be involved for each of them;
- evaluate the measurements and options to make better decisions;
- collaborate with other involved stakeholders;
- gathering the most relevant information in order to detect anomalous events;
- evaluate the decision taken.

Moreover, to enable an effective decision making process, users need a complete overview of the critical situation that means, in terms of data and information, an integration of current (real-time) and past knowledge of critical evolution to better understand the situation in progress. The OWE integrates the following operative tools, services and applications to operate in extreme or high-pressure situations:
environments, establishing necessary and useful functionalities for representing the critical situation and providing information for decision making support.

2.2.1. Sensory Map. The Sensory Map service shows the monitoring areas and the position of the installed sensors. It consists of a 2D map where the icons depict the position of the installed online sensors, and the results coming from the offline sensors with regard to the main areas to be monitored due to the fact they have been affected by main hazards.

The online sensors generally consist of one or more nodes capable of hosting one or more physical sensors, and an aggregator or base station capable of collecting data received by several nodes and sending them to a data gathering module for their collection, storage and management. When the user selects each of the sensors highlighted on the map, several data are shown in a concise form on the map. Further information, such as the latest measure for each sensor and the data provided by all the sensors, are presented as charts in a dedicated section.

The offline sensors are used for scientific surveying activities that can be implemented periodically or after a natural hazard event occurrence, to monitor and assess damage. The offline sensors’ results come from Induced Fluorescence, Terrestrial and aerial Photogrammetry, Laser Scanning, Electrical Resistivity Tomography, Ground Penetrating Radar, Infrared Thermal Imaging, x-Ray Diffraction and Fluorescence, Spectral Camera and so forth. Similarly to the online sensors, the offline sensors’ results are identified on the 2D map, providing both a form with the main information and a detailed section where the specific measurement information details such as images and 3D models, can be shown.

2.2.2. Visual Analytics. The Visual Analytics service gathers (online) sensor network data and other relevant information from the disaster-affected areas and presents the result of their analysis to the user in an effective graphical way. In that view, data are processed to provide easy-to-understand representations considering both past events and the current situation at sites. This feature is essential to identify existing or new risks and to monitor their evolution, starting from the analysis of the current and historical data. This information is then visualised through appropriate charts and maps. The users can visualise the resulting analytics using different features, according to the selected type or to the particular event. For each chosen type, a view of the current trends and evolution of the situation is showed, along with a list of the current recorded events.

Specifically, information provided includes: i) type of the threats and their characteristics (e.g., wind or rain, intensity, direction, occurrences, time-frame, etc.); ii) maps of hazardous events occurred on the site; iii) monitoring of specific measures relative to assets (e.g., humidity, temperature, volume); iv) historical data monitoring of natural events; v) historical data monitoring of specific measures relative to the assets and evolutionary trends. The Visual Analytics service is provided as a Web GIS layer where it is possible to select the preferred site/area/sensor node in order to visualise the associated analytics.

2.2.3. Diagnosis Reporting. The Diagnosis Reporting enables the detection of hazardous events or identifies relevant threats starting from the useful information extracted by processing and analysing data from online and offline sensors. The detection of a damage caused by a hazardous event previously occurred or the identification of some threats that could increase the exposition or vulnerability of an asset against specific hazards can be notified to the platform. From one side, a set of data processing modules automatically detect and alert the user once thresholds are overcame or rules are fired. On the other side, potential damages, events and threats detected by a trained or expert user after analysing the results produced by offline sensors can be manually added into the platform directly using the Diagnosis Reporting service. It provides in addition a set of functionalities for managing (add, delete, update and show) all the events either produced in an automatic and continuous way by the system or manually by an expert user.

2.2.4. Risk Assessment and Management tool. Risk Assessment and Management tool supports the derivation of appropriate risk management strategies developed in the context of STORM. The tool aims
to help the site managers and experts to assess the level of risk in different areas of the site and determine site-specific strategies to mitigate the risk associated with natural hazards and climate changes.

2.2.5. Situation Awareness service. Situation Awareness service provides a detailed view of maps with all the indicators and parameters essential to take under control the situation and assist decision makers. A clear picture of the situation with all the details about vulnerability and risk areas, hazardous events, and other relevant information are visualised in a thematic map in order to identify the impact on a cultural heritage site, its areas and assets. In this way, users can understand the current situation status, having a real-time monitoring on how the situation evolves and enabling a kind of common operational picture.

Situation Awareness service is organised in different views describing dangerous situations that arise when determined events, detected by the system, happen. All the dangerous situations are listed along with their criticality level, status and date through a Web GIS service, making use of specific icons for each relevant information to be shown. Moreover, the current situation is available through an on-map and on-time view, respectively focused on the geographical or temporal dimension. In this way, all the fundamental information is provided to the user, namely a description of the specific damage, the status, the affected site, the temporal range. In addition, a process list to be started for mitigating the situation (First Aid) is visualised illustrating the specific hazards, the involved assets, a brief description and the user that must manage the situation, if already established. Otherwise, the site manager can choose to assign a specific process to a user, acting as team leader.

3. STORM Experimentation

One of the main aims of the STORM project is to provide solutions that can be used in any Cultural Heritage context in Europe and over the world. Therefore, it was of the highest importance that the technologies, services and processes developed in the project could be tested in an appropriate number of different Cultural Heritage sites.

The five pilot sites selected, located in five different countries, are indeed one of the strengths of the project, as they are very different in location, size, historical period, as well as in the threats menacing them and in their conservation problems and needs. Each STORM pilot site has defined experimental scenarios and simulation activities according to the specific needs. The aim of the experimental campaign is to validate the proposed solutions in relation to the three phases defined in the project, covering a comprehensive approach with ex ante planning and prevention, management and actions, and recovery activities. The selected pilot sites are: the Mellor Heritage Project (United Kingdom); the Baths of Diocletian in Rome (Italy); the Historical Centre of Rethymno (Greece); the Roman Ruins of Tróia (Portugal); the Ancient City of Ephesus (Turkey).

A series of seven experiments and trials were performed at Mellor Heritage Project: the first 5 experimental scenarios were carried out throughout the project and focused on using photogrammetry, laser scanning and weather station data against the freeze thaw hazard to intercept damage before the hazard evolves into a bigger issue. The final two experiments were carried out to test the entire STORM process for the following sudden-onset hazards: intense rainfall and high winds and electrical storms. These two experiments were evaluated during a couple of drills at the Mellor site with the participation of volunteers and archaeologists to enact STORM processes.

At the Baths of Diocletian, during the project, a weather station and Fiber Bragg Grating (FBG) sensors were installed, and a laser scanner campaign was carried out in order to test the platform against the following slow-onset hazards: rising humidity, vibrations and biological degradation. Moreover, the Baths of Diocletian organized two drills to test preparedness and first aid response in case of sudden-onset hazards. The first drill simulated the strong wind hazard in the garden damaging two sarcophagi. The second drill was carried out with the intervention of Italian firefighters, archaeologists and restorers and simulated an earthquake of medium intensity damaging an ancient pillar of the building and an ancient sarcophagus.
At the Historical Centre of Rethymno, experiments were carried out using photogrammetry, laser scan, photography camera, conductivity meter, weather stations and accelerographs to test prevention in case of salinization at the Lighthouse in the Venetian Port area. Furthermore, two more exercises to test the processes of dealing with sudden-onset hazards and to improve the preparedness and response actions of all the involved actors were carried out; the former simulated intense rainfall hazard affecting the St. Luca’s bastion in Fortezza Fortress, while the latter simulated an earthquake of medium intensity at the Fortezza Fortress, damaging the watchtower on the corner of St. Paul’s bastion.

At the Roman Ruins of Tróia a number of experiments were carried out using photogrammetry, induced fluorescence sensors and environmental sensors coupled with image recording and crack-meters to test prevention against the tidal and wave action, intense rainfall and biological colonization. Furthermore, two drills to exercise STORM processes for sudden-onset hazards have been performed, simulating coastal erosion and local wind with salinization.

The experimental campaign in Ephesus addressed two main hazards: earthquake as a sudden-onset hazard and prolonged dry periods/heat wave as a slow-onset hazard. The earthquake scenario was approached through two complementary experimental scenarios. The first one tested and validated the technological solutions deployed at the pilot site. The second one involved multiple external actors in order to assess the performance of the emergency response process. Finally, a third scenario tested the process response to prolonged dry periods/heat waves, one of the main risks at the pilot site.

Overall, more than thirty experimental scenarios have been demonstrated at the pilot sites to validate the three levels of STORM outcomes: technologies, services and processes. During the experimental campaign it was demonstrated and confirmed how a good and well-planned prevention is important for the optimal conservation of Cultural Heritage, experimenting new methodologies and treatments, which can be effective for slow-onset hazards management. Furthermore, thanks to the implementation of the ten drills for sudden-onset hazards it was possible to experience how the preparedness can be useful for an adequate and effective emergency intervention. In these situations, the platform proved to be very useful, allowing the professional figures, dealing with the emergency, to have all the necessary information real-time, thanks to all the documentation and data collected before the critical situation.

4. The STORM Platform added values
The challenges in protecting cultural heritage have grown in the past years. Even though on one hand the technological advancements have given us the capabilities of addressing risks and threats, the nature and level of threat of the same risks has grown enormously. Both climate change and human actions are creating new risks, or adding to the old ones, increasing the severity of damage caused. STORM project was the best opportunity to cope with the challenge of merging technologies with human and cultural oriented practices, such as conservation and restoration. STORM has introduced a comprehensive approach that supports end users with transversal services as data analytics and knowledge sharing during all these phases.

The main lessons learnt are related to: 1. the chance to learn the importance of the technical components and of the correct use of any developed technology; the opportunity to understand how technologies, commonly used in other situations, with some modifications and updates, can also be applied for monitoring or protection of cultural heritage; 2. a deeper knowledge of the methodologies in order to keep costs under control even when a cultural site needs to face emergencies; this is certainly possible thanks to an adequate planning of the long term interventions to be carried out in order to mitigate not only the damage to the cultural assets, but also the costs to face them; 3. experience how the preparedness can be useful for an adequate and effective emergency intervention. In these situations, the platform proved to be very useful, allowing the professional figures dealing with the emergency to have all the necessary information in real-time, thanks to all the documentation and data entry work done by the pilot sites to test the platform in real environments with real data. On the occasion of these activities it was also possible to notice how, reusing and adapting some materials which are already present in situ, it is possible to mitigate damage in emergency situations while decreasing the interventions costs; 4. how a good and well-planned prevention is important for the optimal conservation
of cultural heritage, experimenting new methodologies and treatments, extremely low-cost and eco-compatible, which can be effective for slow hazard management.

Nevertheless, the protection of cultural heritage is a never-ending process. In relation to the future market opportunities to be exploited by STORM, mainly small organisations and start-ups could play a relevant role in bringing the innovation in real life. This will probably be done using strategies which could count on local financial support and the possibility to have advanced regulations provided by local authorities. With an estimated cost to run a STORM experiment ranging from 8 to 10k€ (using the platform released at the end of the project), SMEs and start-up focused on this potential business should run several experiments in order, from one side, to assess technologies and prioritise them, and on the other side to consolidate preparedness and first aid methods in order to better fit the site managers’ needs.

Moreover, new professionalisms could grow from the project experience, starting from Cultural Heritage experts such as conservators, restorers, archaeologists, architects, art historian involving specific branches of engineering; that could create new job opportunities for all those people provided that they will receive the proper education and practice experience [5] [6].

5. Conclusions
The main features and consequent benefits of the STORM platform are the creation of an interactive environment that would not only provide opportunities for an exchange of information among users of the system but could also facilitate the establishment of closer links. Another benefit of the platform is the speeding up of the response times, so the right people with the relevant skills are identified more quickly and disaster events dealt with in a faster manner.

Finally, a more effective collaboration between the different actors by interactively involving them in the decision-making process has been established. The STORM pilot experiences have demonstrated the added value of this multidisciplinary work, linking technical and pilot site-oriented objectives on the agreement of a common approach to the experimental campaign, working closely with the aim of Safeguarding Cultural Heritage through Technical and Organisational Resources Management (STORM).

STORM has been a great experience and has increased the awareness on how digital innovation can bring a strong support to the safeguard of our cultural heritage and identity.

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