SIBYL

(**S**e**I**smic monitoring and vulnera**B**ilit**Y** framework for civi**L** protection)

Agreement number: ECHO/SUB/2014/695550

Deliverable DA4: Final technical and financial report

Project start date: 01.01.2015 End date: 31.12.2016

Coordinator: Prof. Dr. Stefano Parolai
Section 7.1 Centre for Early Warning Systems
Helmholtz Centre Potsdam GFZ German Research
Centre for Geosciences, Potsdam, Germany

Table of Contents

General reminder

An essential requirement for Civil Protection (CP) authorities is understanding an area's seismic (or any other hazard) vulnerability in order to undertake risk estimation and response planning, in particular over city or community scales. The most appropriate methods would need to be cost-efficient in terms of both time and resources, while also being sufficiently accurate and reliable, and relatively simple, meaning high levels of specialised training would be unnecessary. Such methods would be employed in the event of seismic swarms or foreshocks, allowing the prompt assessment of the threatened area´s vulnerability. Such actions are especially important for areas that lack reliable and up-to-date building stock information, an issue of grave concern, even in developed economies such as those in Europe.

With these issues in mind, the European Commission Directorate General for Civil Protection and Humanitarian Aid Operations[1] has supported the SeIsmic monitoring and vulneraBilitY framework for civiL protection or SIBYL[2] project. SIBYL set out to develop an operational framework for CP authorities to undertake rapid and cost-effective assessments of the seismic vulnerability of the built environment to optimize disaster mitigation management and emergency response activities. This framework will be utilised in pre-event situations, monitoring the built environment's dynamic vulnerability during a seismic sequence, and in undertaking vulnerability assessments as part of longer-term risk management strategies. The framework (made up of software and hardware tools and various procedural guidelines) will have the flexibility to be applied at different spatial scales, while a modular structure was followed to allow it to be expanded and adapted to other natural hazard types.

The SIBYL consortium is coordinated by the Centre for Early Warning Systems of the Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences (GFZ). The other members are AMRA S.c.a.r.l., (AMRA, Naples, Italy), the Geotechnical Earthquake Engineering Division of the Aristotle University Thessaloniki (AUTH, Thessaloniki, Greece), and the Chair of Structural Mechanics, Technical University – Berlin (TU-BERLIN, Berlin, Germany).

The expected outcomes and deliverables of SIBYL were as follows:

- Hardware and software tools exploitable by CP practitioners with minimum training for acquiring and analysing different observations covering various spatial scales for seismic vulnerability assessments. This will include assessing a structure's dynamic behaviour (and its changes over time) and site effects. The tools include a mobile mapping system and analysis tools for the acquired imagery, the analysis of space borne remote-sensing images, structural appraisal and short-term monitoring procedures (including the installation of instrumentation), site-effects surveys, and assessing time-variant structural vulnerability over different spatial scales.
- The development of guidelines for CP authorities for implementing the framework and using the tools most effectively at various spatial scales and stages of a seismic crisis.
- Demonstrating the developed tools and capacities to CP practitioners and other interested parties as part of capacity building and training actions to more efficiently mitigate against seismic (and other)

---

[1] http://ec.europa.eu/echo/
[2] http://www.sibyl-project.eu/welcome/

hazard and risks. This will serve as the first steps towards opening up opportunities for the implementation and integration of the SIBYL framework into CP operational protocols.

The end result is the belief that the SIBLY products, with proper adaptation to each CP authority’s needs, will enhance CP operational capacities at the pre- and post-event stages, hence ensuring the legacy of the project.

General summary of the project's implementation process

The implementation of the project's activities over its duration has generally gone well and all deliverables have now been thoroughly reviewed and submitted to EC-ECHO. The project activities include the theoretical development of tools and methods and field work in selected test sites and structures, which saw the developed tools and methods tested. The general work scheme is shown in Figure 1.

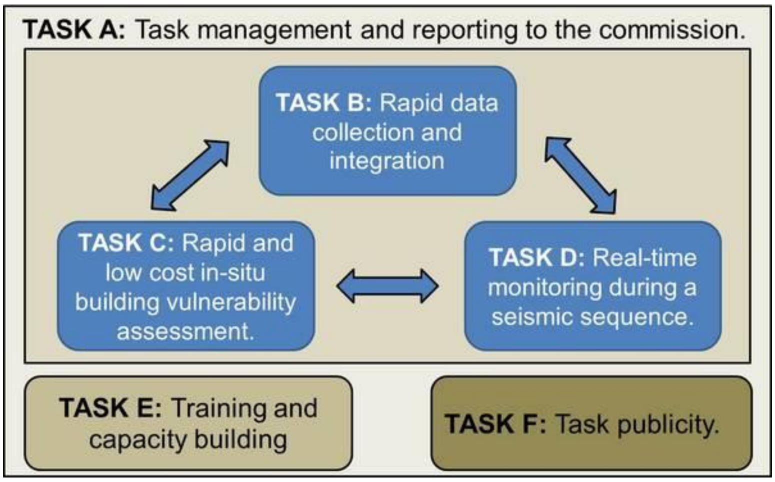


Figure 1 General work scheme of the SIBYL project, showing the interrelationships between the various tasks.

In addition to the project's overall management (Task A), the GFZ activities were mainly centred on the development/expansion of methods for exploiting remote sensing imagery, further development of the Remote Environmental Mapping (REM), advancements in the MPwise (Multi-Parameter WIreless SEnsing) system, a self-contained unit for data recording, processing and transmitting that can be linked with different sensors, depending upon the parameter required to be measured. In addition, GFZ was responsible for the capacity building (Task E) and dissemination (Task F) activities.

The work of AUTH (mainly within Task C) aimed at the development of an operational framework that could be used by, e.g., CP authorities and other end users in pre-crises situation to establish decision-making procedures and risk mitigation strategies. Based on the proposed assessment framework, the seismic vulnerability of existing buildings is evaluated by combining, through a comprehensive methodology, the numerical analysis and field monitoring data. Two buildings from the AUTH campus in Thessaloniki were selected as case studies (see below), which involved building monitoring and site assessment.

AMRA was responsible for Task D "Real time monitoring during a seismic sequence". This Task was concerned with the development of methodologies and practice-ready algorithms for building tagging and time-variant risk assessment. As indicated in the project plan, AMRA supported heavily the activities of Task C "Rapid and low cost in-situ building vulnerability assessment". In particular, AMRA was significantly involved in the field activities in central Italy. AMRA had also played a major role during the organization of L'Aquila workshop.

TU-BERLIN was primarily engaged in Task C, developing procedures for the in-situ inspection, measurement of structural features and the acquisition and analysis of ambient noise recordings. This included the development of an excel-based analysis tool that allows the modelling of real buildings without the need for computationally expensive finite element models.

Field activities undertaken as part of SIBYL were carried out in Thessaloniki, Greece, Cologne, Germany, and Central Italy.

- In September/October 2015, field measurements were undertaken at the Thessaloniki test site by GFZ, TU-BERLIN and AUTH. The measurements involved instrumenting the Administration and Faculty of Philosophy buildings of the AUTH to record ambient vibrations. The TU-BERLIN software for collecting and archiving topological and structural information was tested during this time. In addition, a set of passive 2D array measurements was carried out for site assessment (deriving the shear wave profile and obtaining the so-called V_{s30}, the average S-wave velocity in the top 30 m). These preliminary measurements have been useful for defining the steps of the procedures (field measurements, data analysis) developed in SIBYL, and which have been integrated in the associated software. Amongst the other activities, a thorough maintenance of the SOSEWIN[3] units already installed in these two buildings, as well as the AHEPA[4] hospital was conducted.
- In November/December 2015, field measurements were undertaken in Cologne by GFZ and TU-BERLIN. The aim was to make *in situ* engineering measurements and observations of the main buildings of selected schools in the Cologne area, including noise measurements, and to carry out ambient noise measurements via arrays of MPwise instruments for site assessments at or close to the schools (again determining the V_{s30} parameter). Seven schools were inspected, prior to which exchanges were made with the authorities responsible for the schools' safety. These authorities in fact showed a great interest in the project's goals and outcomes. Discussions were also held with school principles to explain the rationale behind these activities. In addition, a representative from the Bundesanstalt Techniches Hilfswerk (THW[5]) inspected the activities on the last day and had the reasoning behind this deployment explained, the instruments used shown and some of the processing tools being developed by the project demonstrated. The Cologne field measurements also served as the first test-bed of the MPwise system in combination with the SIBYL toolbox for real-time array processing and building monitoring under realistic conditions.
- An extra field excursion was undertaken in September, 2016 by a team from GFZ in Central Italy to undertake a mobile camera survey of the area affected by the Mw 6.2 August 2016 event. The aim was to test the data and image collection and processing tools being developed in SIBYL under realistic conditions. The work was supported by the Italian Civil Protection Authority[6] and carried out in collaboration with INGV (Istituto Nazionale di Geofisica e Vulcanologia[7]).

The deliverables provided to the EC-ECHO underwent an internal review process, whereby a deliverable that was the responsibility of a given partner upon completion was forward to another partner (who was not involved in its production) for review and comment. This procedure generally proved to be successful, and for most deliverables was the one followed, although for some, it involved the entire consortium contributing (e.g., those deliverables outlining the dissemination activities). In addition, smaller informal reports of most of

---

[3] Self Organising Seismic Early Warning Information Network – see Fleming et al. (2009).
[4] http://www.ahepahosp.gr/en_index.asp
[5] https://www.thw.de/DE/Startseite/startseite_node.html
[6] http://www.protezionecivile.gov.it/jcms/en/home.wp
[7] http://www.ingv.it/en/

the field activities and the meetings were produced and forward to the EC-ECHO science officer as well as being available on the project website.

Communication within the consortium was effective, due to the clear structure of the project and in part to the partners having, to varying degrees, been involved with each other in previous projects.

Considerable contact between the partners and representatives of the Civil Protection (CP) authorities of the relevant countries (Germany, Greece and Italy) has also seen the goals and outcomes of the project be broadly disseminated. Common meetings and workshops helped in disseminating the progress of the project and the final outcome and products to end-users, while at the same time end-users introduced to the consortium their valuable expertise and practical constrains and needs. The CP representatives participated in the project via project meetings, workshops, and during the field activities. In particular, the workshop in l'Aquila Italy (May, 2016) allowed the project's products and goals to be outlined in greater detail, including a demonstration of such products as the mobile mapping system.

Other dissemination actions included the project website, teaching activities (i.e., Masters theses based on the SIBYL output), and the publication and presentation of the project's results in the appropriate literature and conferences.

Evaluation of the project management/implementation process

As commented upon in the previous section, the general implementation of the project is believed by the consortium to have proceeded smoothly, owing not in a small part to the consortium members having worked previously together. This led to any research or technical difficulties arising being more easily solved by direct communication between the involved participants, with little intervention required by the management. With regards to issues that arose requiring confirmation/advice from the EC-ECHO (generally concerning the reallocation of funds within each partner's budget), this was readily dealt with by the management and project officer in Brussels. In fact, during the final meeting in Potsdam which the project officer attended, he stated that he believed the level of communication that went on between EC ECHO and the consortium was appropriate, and he was very satisfied with this aspect of the project management.

The main discrepancy that occurred between the original project plan and what was undertaken during the project concerned the amount of travel that was expected. For example, scheduling issues did not allow as many collaborative working visits among partners as originally planned. To partially counter this, several initially unplanned actions were undertaken, namely, the workshop in l'Aquila and the field activities in Central Italy following the damaging August 24th 2016 earthquake (see below).

The management oversaw the quality control process of the deliverables described in the previous section, while also undertaking a final check of the documents. This procedure, which in the experience of the management from previous projects is the most effective means for maintaining and further developing the quality of the work undertaken, will be expected to be followed in future projects.

Communication between the consortium and the CP authorities who were engaged in the project via the periodic meetings, workshops and fieldwork was overseen and encouraged by the management. The value of such interactions was not only the dissemination of the project's goals and results, but also to gain a better understanding of what exactly would be required by CP practitioners.

There is high hope that such communication will continue, especially within the context of the next series of calls for proposals where the input from CP and other stakeholders will allow the future design of research programs to be more relevant to the specific needs and capacities of the stakeholders and CP authorities in various EU countries.

All payments received from the EC-ECHO were distributed amongst the project partners within an acceptable time period. In terms of the expenditure, owing mainly to the less travel than planned, the project underspent by 45,892€.

The following lists the more major modifications to the budget from the original plan. It should be noted that all changes were only of the order of several thousand euros, well below the €30,000 limit, after which more formal approval from the EC-ECHO is required. In general the changes (for most partners) had to do with the reallocation of funds to personal, as well as the travel funds, as explained above, not being as extensively used as originally planned.

- GFZ reallocated 3,650€ from Travel to Personnel, and 3,750€ from Travel to Subcontracting (SIBYL workshop in L´Aquila).

- AUTH reallocated 4,000 € from Travel to Personnel due to additional analyses for the vulnerability assessment at the monitored buildings being required, and the processing of seismic records for the same purpose (Task C) (e-mail sent on 24/6/2016). In addition, 910€ from Other Costs to Equipment, due to some additional expenses arising from the support of the communication and the data archiving of the 6 SOSEWIN instruments working at the two buildings (initially asked on 1/12/2016 for *ca*. 800€).
- TU Berlin and AMRA both saw no shifts in funds between categories, only underspending with respect to the original budget plan.

Activities

In the following we outline the specific activities that were undertaken during the course of the project, including those already presented in the interim reports (DA2 “First progress report”, and DA3 “Second progress report”).

- The project’s website was established and is being continuously updated. It is expected to be maintained for at least two years (see deliverables DF1 “Project website”, DF3 “Report on public outreach events/activities” and DF4 “Report on technical and professional outreach”).
- Real-time software tools for seismic array analysis for site assessment (e.g., V_{s30}) and building response modelling and analysis have been developed and tested (see deliverables DC1 “Guidelines for the building assessment procedure and short-term monitoring” and DC2 “Guidelines for undertaking site-effect surveys”). These tools are designed for use with the MPwise sensor units, allowing immediate preliminary site assessments (e.g., V_{s30}) and structural characterisation.
- Field activities involving structural monitoring and measurements and site assessment were carried out in Thessaloniki (September-October, 2015), Cologne (November-December, 2015) and L’Aquila (May, 2016) by AUTH, TU-BERLIN and GFZ (see deliverable DC4 “Reports on the case studies”). Associated with these actions were demonstrations to local CP representatives, discussions with authorities responsible for the safety of schools (Cologne) and meetings with representatives of the schools that were surveyed in Cologne, as well as explaining our activities to school students and teachers.
- The field work also involved collating the blueprints and plans of the selected Thessaloniki test buildings, with AUTH undertaking a numerical analysis of the refined 3D-model and TU-BERLIN using the supplied information for simplified structural modelling and seismic vulnerability assessment. Plans for some of investigated school buildings in Cologne were provided by school administrators.
- Extensive analysis of the field surveys to estimate soil-site properties and structural monitoring to assess the seismic performance of the instrumented buildings in Thessaloniki to finally derive the buildings’ and time specific fragility curves has been conducted by AUTH.
- A workshop to present and demonstrate the SIBYL products to CP representatives (various Italian, Greek and Italian groups) was held in L’Aquila, Italy, from the 30th to 31st May, 2016. The two day workshop involved talks introducing the project and outlining the work being undertaken, described the tools (hardware and software) under development, and the field work already completed. Some demonstrations were carried out, in particular the GFZ-REM (Remote Environmental Mapping) suite of tools, making use of buildings damaged during the 2009 L’Aquila earthquake.
- In September, 2016, a team from GFZ travelled to Central Italy to carry out a mobile camera survey of the area stricken by the August 2016 Mw 6.2 Central Italy earthquake. This work was an opportunity to test, in a realistic situation, the data gathering and processing tools being developed and expanded upon in SIBYL. The work was undertaken in close collaboration with INGV (Istituto

Nazionale di Geofisica e Vulcanologia[8]) and the support of the Italian Civil Protection Authority. The collected images are currently being analysed by INGV personal.

- A structural reliability assessment model based on a Markov-chain-based approach was developed, which is able to account for changes that arise in a structure's seismic response due to damage. The model can also account for hazard variability during an aftershock sequence according to consolidated seismological models. Once the model has been calibrated on the characteristics of the considered structure, it requires very limited computational power.
- Several procedures for in-situ data collection and recording have been developed and tested for structural modelling and building assessment, taking into account different information availability scenarios, ranging from "no knowledge" to "detailed knowledge". These procedures usually include or more on-site visual surveys, structural survey, several means of undertaking geometrical measurements and non-destructive material testing, as well as short-time ambient vibration monitoring. The data obtained on-site serves as input for a simplified structural model and rapid vulnerability assessment implemented in the MS Excel program.
- A number of project meetings were held.
- Kick-off meeting in Brussels in January, 2015, where all projects supported under the **2014 Call for Proposals for Prevention & Preparedness projects in civil protection and marine pollution** were presented.
    - Start-up technical meeting in Potsdam, 28 January 2015.
    - Mid-term meeting, Thessaloniki, 15-16 February, 2016.
    - Final meeting, Potsdam, 07 December 2016.
- The SIBYL project was also presented at several conferences (see the report on Task F "Task publicity"), with a number of academic publications being produced/submitted/in production (see reference list and report for Task F). In addition, SIBYL was outlined at other relevant meetings, for example, Prof. Pitilakis (AUTH) discussed the goals of SIBYL at a meeting of the European Committee of Normalisation for the revision of Eurocode 8 (Paris, France, March 2016) and with EC officers regarding future H2020 calls relevant to SIBYL.

---

[8] http://www.ingv.it/en/

Presentation and evaluation of technical results and deliverables

Task B “Rapid data collection and integration”

The deliverables for this task were DB1 “Guidelines for the remote-sensing assessment methodology”, DB2 “Software platform including processing tools with related manual”, and DB3 “Guidelines of the mobile mapping system and remote rapid visual screening”. The work carried out (mainly by GFZ) built upon previous EC funded projects, in particular the FP7 SENSUM[9] (Framework to integrate Space-based and in-situ sENSing for dynamic vUlnerability and recovery Monitoring) project.

The first point to make is that all three deliverables are interwoven and that they describe specific aspects of an overarching system. The development of this system stems from the observation that in real-world risk-assessment applications, the exposure and vulnerability models play a critical role, where poor (incomplete, sparse, uncertain) knowledge of these factors of a geographical area exposed to natural hazards, such as earthquakes or floods, will certainly result in uncertain and potentially misleading estimates of the expected consequences. Such information must therefore be relevant, reliable, and up-to-date. Being able to collect exposure information efficiently at multiple geographical and temporal scales will thus allow risk practitioners to move towards more sustainable assessment schemes.

The development of exposure models traditionally entails the collection of a significant amount of data in the field, with engineering procedures that have been developed for individual (usually critical) structures. Since these procedures do not scale well with the geographical extent of a risk-assessment application, the resulting burden (both economical and in terms of resources) may hinder the whole process. This further describes the value of the SIBYL project, in that it is setting out to provide methodologies, technologies and tools able to streamline the exposure modelling process while ensuring a satisfactory level of accuracy and timeliness. In addition, there is the need for such methods and tools to be exploitable by interested parties with minimal training. One critical point that should be mentioned is that the development will follow as far as possible the Free and Open Source Software (FOSS) dissemination concept. This is to allow the most widespread distribution of the developed products for the minimum of cost, a process that was followed in projects like SENSUM owing to there being partners from less economically developed countries in Central Asia.

The first deliverable, DB1, aims to guide and assist a non-skilled user in the process of collecting, processing and interpreting remote-sensing data within the framework of exposure and vulnerability assessment. While remote sensing for vulnerability assessment is less established within hazard and risk studies, nevertheless, a great deal of research has been undertaken involving the derivation of pre-event vulnerability indicators that can be related to physical, demographic and socioeconomic aspects of vulnerability.

In order to provide easy-to-use, but effective tools to CP authorities, within the SIBYL project, simpler approaches have been preferred to sophisticated solutions. While the latter may provide very accurate results, they are also bound by complex operational settings and are strongly dependent on the expertise of the users. Therefore, a simple plug-in for the well-known Quantum GIS (QGIS) platform[10], termed SATEX

---

[9] http://www.sensum-project.eu/de

[10] http://www.qgis.org/en/site/

(SATellite EXposure information extraction), has been implemented to carry out a supervised land-use/land-cover (LULC) assessment using medium resolution multi-spectral images. LULC provides a useful partitioning of an area of interest into different classes which represent the basic attributes of the territory in question. Such information can then be exploited in order to improve the efficiency of in-situ data collection activity, for example based on the mobile mapping system (see deliverable DB3).

The developed SATEX tool is designed for medium resolution, multispectral Landsat[11] imagery owing to the fact that Landsat images are global in coverage, free of cost, and the most recent sensors feature a geometric resolution adequate for different operational scales, ranging from the block-scale to the regional scale. Moreover, despite the geometric resolution being significantly lower than some commercially available products (e.g., Google Map applications), the information contained in the multiple spectral bands provides very rich content that can be more efficiently exploited by the statistical learning approaches implemented in the software.

However, SATEX is also developed with the Sentinel[12] series of earth observing missions in mind, further enhancing our ability to assess vulnerability (and its dynamic nature) from space. The SATEX plugin provides two algorithms or modules for processing individual or multiple Landsat images: (1) Preprocessing and (2) Classification. The pre-processing module defines the area of interest from the images and stacks the separate spectral bands (Figure 2).

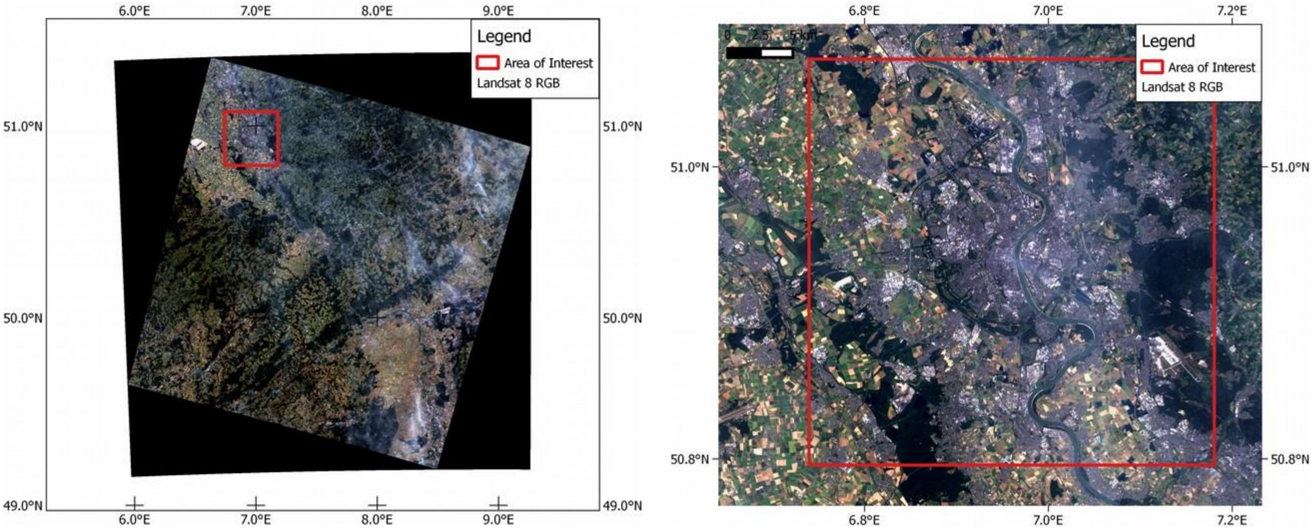


Figure 2 (left) An example of a full Landsat image 8 image, covering an area of approximately 10,000 km^2. The red square is the area of interest (right) which covers the city of Cologne, one of the SIBYL test sites.

From this stacked file, the Classification algorithm would be applied. This module is fed with a small set of labelled examples (a simple procedure that can be carried out in a few minutes in the same software environment) that are used to train a statistical classifier. The output of the procedure is a model which can be used to assign the most likely label to each of the pixels of the input image (see, e.g. Figure 2), according to their spectral features. Details are provided (including the actual installation and running of the tool) in deliverable DB1.

---

[11] http://landsat.usgs.gov/

[12] http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4

The classified image, exemplified in Figure 3, immediately conveys useful information about the urban structures in the considered area, and may then be used to optimize the in-situ survey, for instance guiding the survey in such a way as to visit all different urban typologies (or a subset, e.g., discarding commercial or industrial areas from the survey).

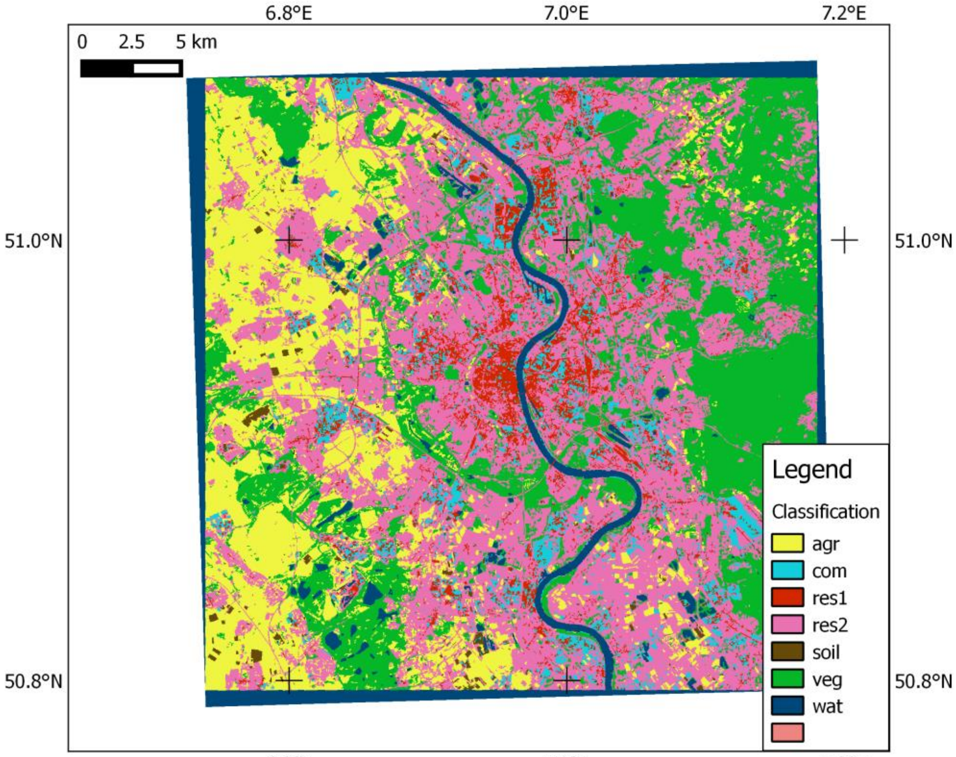


Figure 3 Resulting pixel-based classification of the input Landsat image corresponding to the area of interest marked in Figure 2. The pixels are coloured according to the specific class estimated by the statistical learning machine.

Deliverable DB2 describes a set of tools that have been expanded upon and developed for the purpose of optimising the in situ data collection activities within the SIBYL project. This involves the extension and refinement of a platform referred to as the Rapid Environmental Mapping (REM) system. REM aims to provide a modular and efficient solution for CP agencies and other risk practitioners concerned with natural hazards. The main components of the REM are shown in Figure 4.

The core of the system is represented by the database, which hosts the assets data (geometry, attributes and qualifiers) and the collected images. The database model has been designed for the efficient storage and management of data at different spatial scales, which changes over time, forming the basis of a multi-resolution sampling framework. It is able to integrate and manage various kinds of indicators that follow possibly different standard taxonomies which are, moreover, likely to depend on the type of hazard and/or on the considered phase of the disaster management cycle (pre-disaster vulnerability, post-disaster recovery and reconstruction). In its current implementation, the model could be validated against the GEM building taxonomy[13].

---

[13] https://www.globalquakemodel.org/resources/publications/technical-reports/gem-building-taxonomy-report/

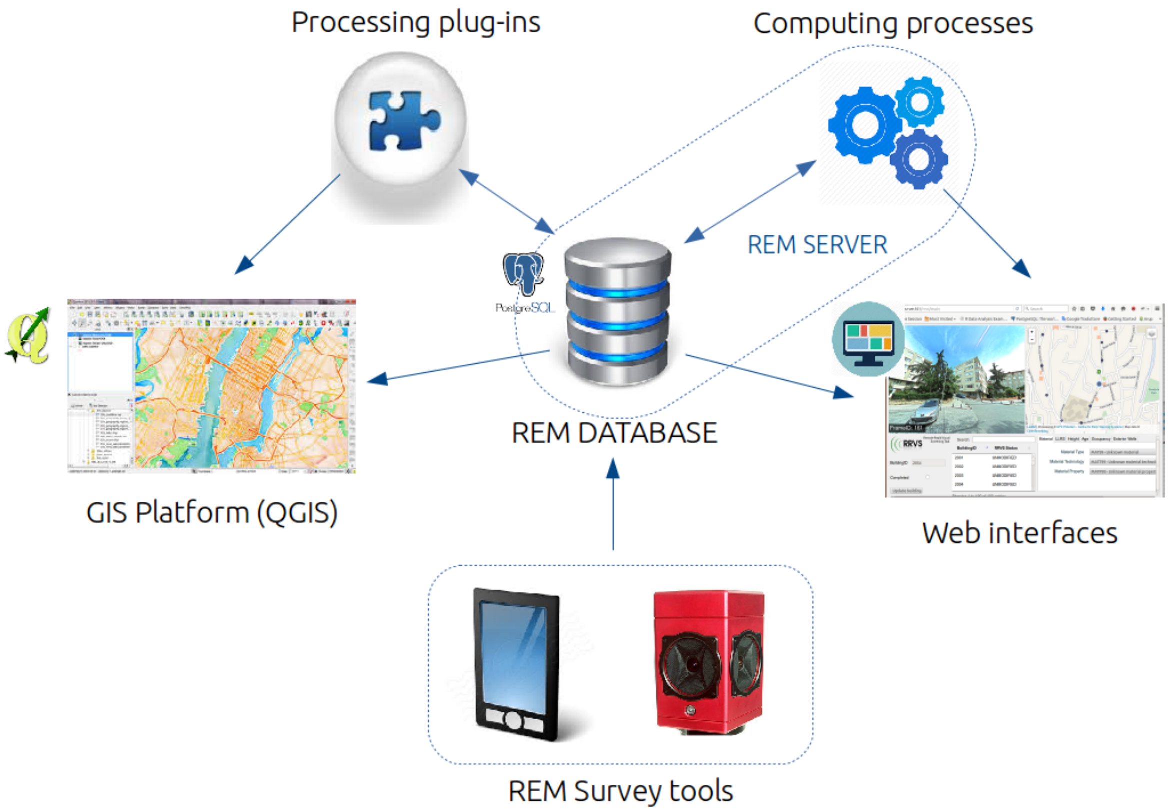


Figure 4 The main components of the REM (Rapid Environmental Monitoring) platform. The REM survey tools and web interfaces are discussed in deliverable DB3.

As can be seen in Figure 4, the database supports and is supported by a number of components:

- The *computer processes* are related to the operation of the management system, the PostgreSQL[14] system, which supports most Structured Query Language (SQL[15]) constructs.
- The *processing plug-ins* are the actual tools used to undertake the processing. The two most important are the SATEX (or REM_SATEX) described above, and the REM optimised routing tool (REM_ORT). REM_ORT takes the stratified images produced using REM_SATEX to define an optimised route for the mobile mapping system (see below). What is required is an adequate sampling distribution on the ground which samples the geo-cells of the considered area according to their classification and which is proportional to their surface coverage, as shown in Figure 5 (for the same area covered in the Figure 3). To optimize the routing, a number of sample points are randomly selected from the sampling set defined above, and are used to select a related set of road segments that will make up the path of the mobile mapping system. However, it is also important to define in which order to visit the selected road segments to make the data collection time- and cost-efficient, while considering issues such as driving restrictions (accessibility, turn-restrictions, one-way streets, etc.). This results in the need to find the route through all the ordered stops that minimizes a cost function (i.e., similar to the famous “Travelling

---

[14] http://www.postgresql.org/

[15] SQL refers to a standard computer language for relational database management and data manipulation, and is used to query, insert, update and modify data.

Salesman Problem", TSP, Abraham and Roddick, 1999), while considering the restrictions imposed by the road network. The input data for the routing operation is an appropriate road network dataset, often available from qualified institutional sources, although FOSS alternatives such as OpenStreetMap[16] (OSM) may also be exploited.

To solve the TSP, a routing engine can be implemented directly on the database (server-side) which employs a set of custom functions for advanced routing operations. The functions include, amongst others, a multiple Dijkstra algorithm to determine the best route through a series of stops while minimizing the cost function. Once identified, the route stops are fed into the routing engine and the TSP solver is applied, where the cost-factor to be used is defined as an attribute in the street network data. A Dijkstra algorithm (Abraham and Roddick, 1999) is than applied multiple times between the sorted stops in order to calculate the shortest path across all the stops.

The routing engine can be successfully used to optimize the implementation of the planned survey while accounting for different time and cost- constraints which can significantly impact upon the required resources. For instance, placing a penalty on the repeated scan of the same street would force the routing engine to enlarge the geographical scope of the survey, potentially adding additional useful observations to the planned ones. Also, highly dynamic parameters, such as, for instance, real-time traffic information, might be considered in the routing phase which could also be conducted *in situ* using a mobile platform. This would also allow the mobile mapping system to adapt to changed environmental conditions without losing the general focus of the survey. An example of the final routing is shown in Figure 6 . Further details on the operational application of the plugin can be found in the Appendix B of deliverable DB2.

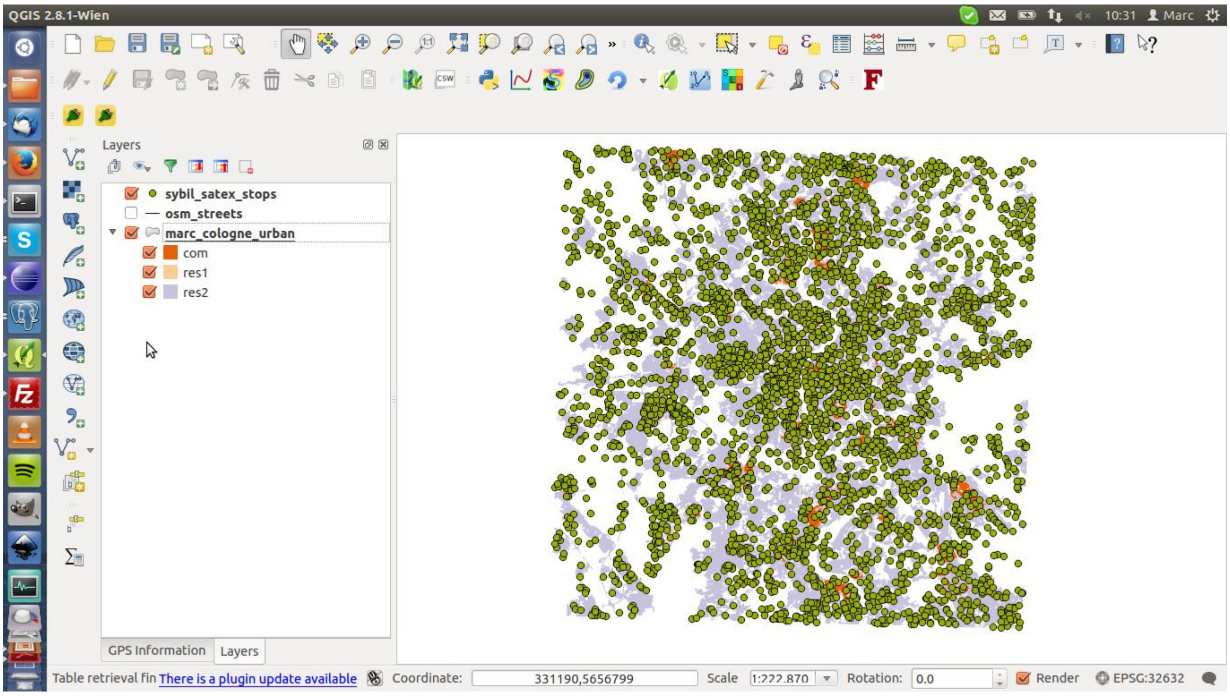
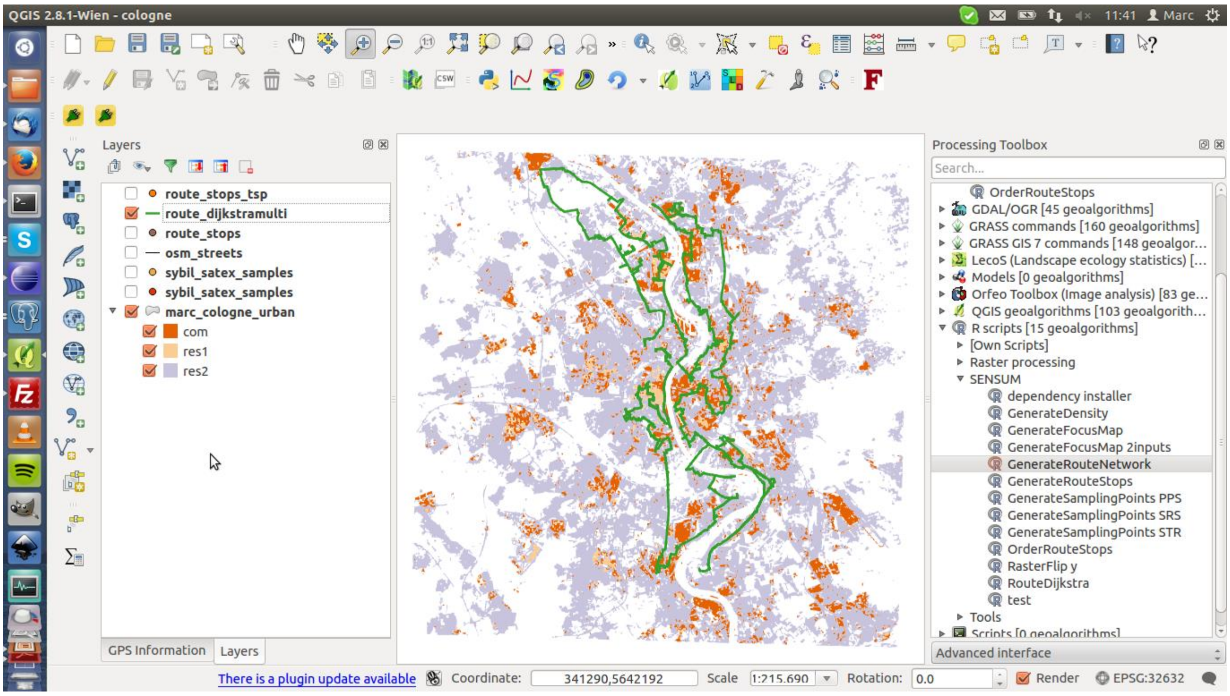


Table retrieval fin There is a plugin update available Coordinate: 331190,5656799 Scale 1:222.870 Rotation: 0.0 ☑ Render EPSG:32632

Figure 5 Generation of stratified sampling distribution, with proportional allocation according to the considered classes. The example is the city of Cologne, Germany (see Figure 3).

---

[16] http://www.openstreetmap.org



Coordinate: 341290,5642192
Scale 1:215.690
Rotation: 0.0

Figure 6 Final optimized route implementing the desired sampling on the ground (see Figure 5).

- The REM uses the *QGIS platform* discussed above to run the plugin-ins and to visualise the resulting maps/results.

- The *REM survey tools* consist of the GFZ-MOMA (MObile MApping) system (Figure 7), which is made up of a high-resolution omnidirectional camera and related acquisition unit and mechanical support (i.e., GPS for location and timing, a power supply), which allows for the rapid acquisition of georeferenced panoramic images that can then be analysed off-line. The camera (Ladybug3[17]) is made up of 6 colour Complementary Metal Oxide Semiconductor (CMOS) sensors that capture concurrent image sequences with an acquisition rate of up to 15 fps (frames per second). These images are synchronized and stitched into an omnidirectional (panoramic) high resolution (5700x2700px) format with JPEG compression. The camera system is operated from inside a vehicle and is mounted on its roof by a simple system comprising a light-weight aluminium frame and 4 high-power suction cups.

  The data capturing and storage unit has been designed and developed by GFZ with a specific focus on ease of use and ruggedness for robust outdoor applications, even under difficult conditions (e.g., unpaved roads, dust). The main component of the unit is a standard notebook with a 750GB Serial ATA hard drive. A commercial-grade GPS receiver provides geo-localization. An optional Inertial Measurement Unit (IMU) can be used to record additional data about the camera’s orientation. The notebook and all other components are fixed into a rugged hard plastic case. A custom-designed software application captures, synchronizes and saves the different data streams coming from the camera, the GPS and the IMU. The synchronization of the data, within 125 msec, is based on the timer embedded in the ieee-1394B hardware controller. Location is associated with each omnidirectional image by a b-spline interpolation of GPS positioning.

---

[17] https://www.ptgrey.com/ladybug3-360-degree-firewire-spherical-camera-systems

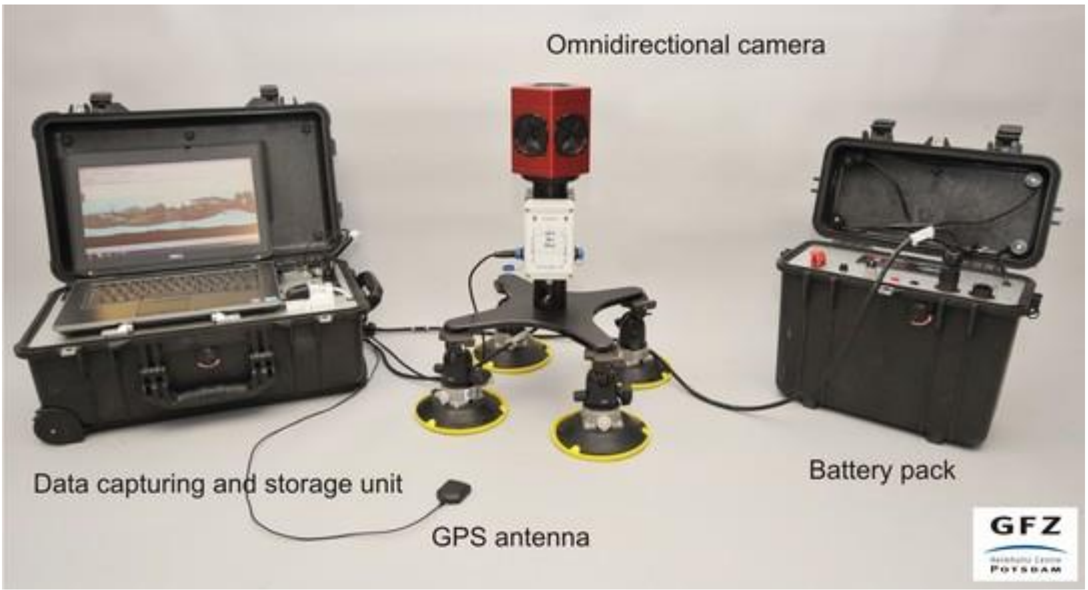


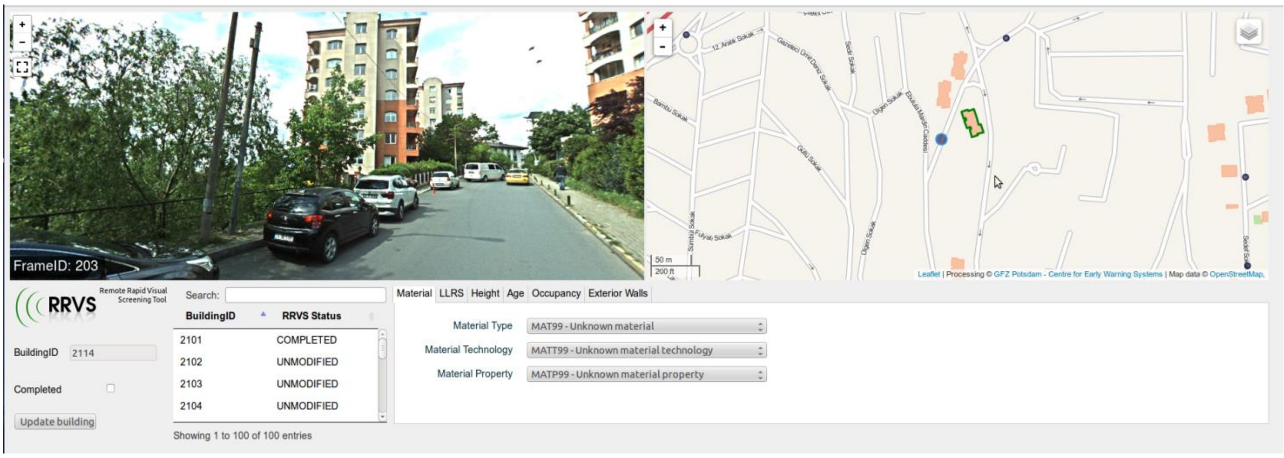
Figure 7 The GFZ-MOMA omnidirectional mobile mapping system, with data capturing and storage unit, omni-directional camera, GPS antenna and battery pack.

The navigation unit uses geographical information systems (GIS) software as the main component for location tracking and car navigation. Its map interface is able to combine various background maps of the study area and to display pre-calculated sample areas and routes. The position can be tracked and displayed in real time with the GPS live tracking functionality. This allows an operator to not only navigate the car along pre-calculated routes, but also to reschedule the path on-the-fly to cope with unexpected environmental conditions (e.g., traffic jams or road blockages). All necessary software for capturing, storing, processing and visualizing the omnidirectional images recorded by the GFZ-MOMA system is provided with the system itself.

The operation of the system is relatively straightforward, and does not require special skills, nor particular tools or additional devices. The system can be easily mounted on different vehicles, including, for example, cars, vans and vehicles from Civil Protection and fire brigade units.

- The *web-based interfaces*, known as the REM RRVS (Remote Rapid Visual Survey) web platform (Figure 8), allows different operators to access the REM database from remote, analyse the panoramic images provided by the GFZ-MOMA and fill in the visible attributes of selected buildings. The type of operator will again reflect efforts made by the SIBYL developers to ensure that non-specialists may quickly learn how to operate the system. However, naturally if the operator is, for example, a local engineer who is familiar with the specific engineering practices in the region of interest, greater value can be gained from the analysis. The analysis will be based on the taxonomy of use, e.g., the GEM taxonomy for seismic hazard, although this can be envisaged to be expanded to other hazard types (see deliverable DE2 “Report on the potential for the developed system to be transferred to other hazard types”).

  The main task of the RRVS tool is to quickly associate to each imaged building, described by its geographical coordinates or by its footprint in a GIS model, a set of structural and non-structural features included in the particular taxonomy considered. This information can then be used in the analysis phase to estimate the structural typology of the building, and its expected vulnerability with respect to an earthquake or some other natural hazards. A valuable aspect of the system is that several operators can be working on a given dataset. This would allow, for example, in the event of a crises, following the collection of the images, a group of specialists to more quickly analyse the images by working on a subset of the buildings to be inspected. All elements of the interface are interactive. For instance, a user can click on an image icon in the map panel in order to load the corresponding image in the panoramic visualizer. Clicking on a building´s footprint in the map, the corresponding information will be queried in the database and will be used to populate the taxonomy tabs for reviewing and modification.



BuildingID 2114

Completed ☐

Search:

BuildingID	RRVS Status
2101	COMPLETED
2102	UNMODIFIED
2103	UNMODIFIED
2104	UNMODIFIED

Showing 1 to 100 of 100 entries

Material Type: MAT99 - Unknown material

Material Technology: MATT99 - Unknown material technology

Material Property: MATP99 - Unknown material property

Figure 8 Web-based interface of the RRVS (Remote Rapid Visual Screening) Tool. On the upper left, an omnidirectional image visualizer allows the user to undertake interactive browsing of the panoramic images. On the upper right, an interactive map represents the selected buildings footprints and the available panoramic images, superimposed on an environmental map.

Deliverable DB3 presents guidelines for the use of the GFZ-MOMA and RRVS described above. The sorts of scenarios that are in mind when considering these tools, and the specific interests of SIBYL are as follows:

- Induced seismicity: for example, what sometimes occur during anthropogenic activities such as geothermal operations (e.g., Deichmann and Giardini, 2009). Such activity would naturally be of concern to populations that had, until then, not been (at least knowingly) exposed to seismic hazard. CP authorities therefore may be called upon, however, there is likely to be little or no information on the expected seismic vulnerability, which would prevent a rapid estimation of seismic-induced damage. In fact, the methodologies developed within SIBYL are being utilised in a H2020 project DESTRESS[18] (Demonstration of soft simulation treatments of geothermal reservoirs) with this purpose or situation in mind. The methods developed in SIBYL could therefore be used after a series of induced events to rapidly evaluate the vulnerability of the built environment and subsequent changes.
- Uncontrolled urbanization: an example of this would be a large town in an economically developing country that is subject to rapid and uncontrolled urbanization (urban sprawling) which has radically changed its exposure and vulnerability to different natural hazards. The precursors to the GFZ-MOMA and RRVS have been employed in this situation within previous projects, for example SENSUM.

---

[18] http://www.destress-h2020.eu/home/

- Post-disaster assessment: this case would be if an earthquake strikes an urbanised region, and a timely and reliable preliminary assessment of the amount and extent of damage is required to better plan the emergency management and the first recovery actions. As mentioned in the Activities section of this report, this was actually undertaken during SIBYL, when a GFZ team with the GFZ-MOMA travelled to Central Italy in September 2016 to carry out a survey of some of the areas affected by the August 2016 Central Italy earthquake, taking this opportunity to test within a realistic situation these tools.

Deliverable DB3 outlines the so-called collection strategy of the REM. This calls upon several key concepts:

- Large-scale data extracted from remote sensing are used to obtain a preliminary characterization of the area of interest.
- Finer-scale information must to be collected from various sources, including in-situ observations, which may involve following a statistical sampling approach. The street-view observations over finer scales provide an initial characterization of the built-up environment which can be integrated with smaller scale information from different sources.
- The use of the GFZ-MOMA system along the optimized route inferred using REM-ORT allows for a rapid collection of georeferenced visual information which can be analysed off-line and remotely.
- Further direct observation of target structures is carried out based on the results of the first characterization phase, and has to be seamlessly integrated into the overall information lifecycle.

The basic steps for carrying out a REM survey are as follows and are outlined in the deliverable.

1. Stratification of target areas using remote sensing analysis (employing the SATEX tool discussed above and in deliverable DB1).
2. Sampling and optimized routing, making use of the REM-ORT, again discussed above and outlined in deliverable DB2.
3. Visual data collection through the GFZ-MOMA system.
4. Analysis of data collected through the REM RRVS (Remote Rapid Visual Screening) web platform.

Further details are given in these deliverables and their appendices.

Task C “Rapid and low cost in-situ building vulnerability assessment”

The goal of Task C was the development of rapid, low-cost and scientifically well-founded approaches for assessing the seismic vulnerability of existing reinforced concrete (RC) buildings, both residential and public. The procedures developed conform to existing design and construction rules of practice and are suitable for undertaking a series of preventive checks of RC buildings in areas of seismic risk over a short time (1 day per building), as well as for building damage assessment after earthquakes. The developed approach enables CP authorities to prioritize their classification of buildings with respect to seismic vulnerability and to estimate the damage extent for future seismic events. This led to the production of four deliverables: DC1 “Guidelines for the building assessment procedure and short-term monitoring”, DC2 “Guidelines for undertaking site-effect surveys”, DC3 ”Documentation for the developed software tools” and DC4 “Reports on the case studies”.

Within this task, three on-site campaigns were undertaken. The aim of these campaigns and associated studies was to offer reliable and high quality data from typical structural case studies to check and validate the accuracy of the simplified low cost and rapid methods of estimating building vulnerability.

The first campaign took place at the end of September 2015. A temporary instrumentation array was deployed by AUTH in close cooperation with TU-BERLIN and GFZ. These instruments were installed in two buildings of the AUTH campus: the Administration and the Faculty of Philosophy buildings, both being designed with low seismic code provisions (Figure 9).

Administration building

Faculty of Philosophy

Figure 9 The Administration (left) and the Faculty of Philosophy (right) buildings of the AUTH, which served as test sites for the project.

The second campaign has been undertaken in Cologne, Germany in November – December 2015. With help of the local municipality and school administration, a direct contact was established with seven schools, whose administration showed an understanding of the problem and interest in cooperation. The list of the investigated schools is presented in Table 1.

Table 1 The schools in Cologne that were surveyed as part of the SIBYL project.

	School	**Building**	**General information and estimated seismic vulnerability**
1	Humboldt-Gymnasium Kartäuserwall 40, 50676 Köln 0221 22191911		Year of construction - 1956 Number of schoolchildren - 1200 Structural system – mixed, RC, masonry Vulnerability class - C
2	Alfred-Müller-Armack Berufskolleg Brüggener Str. 1, 50969 Köln 0221 8201350		Year of construction - 2007 Number of pupils – 3000 (800) Structural system – masonry shear walls Vulnerability class - C
3	Henry-Ford-Realschule Karl-Marx-Allee 43, 50769 Köln 0221 9703400		Year of construction – ca. 1965 Number of schoolchildren - 850 Structural system – mixed, RC, masonry Vulnerability class - C
4	Berufskolleg Ehrenfeld Weinsbergstraße 72, 50823 Köln 0221 9514930		Year of construction – ca. 1960 Number of schoolchildren - not specified Structural system – mixed, RC, masonry Vulnerability class - C
5	Otto-Lilienthal-Schule Albert-Schweitzer-Straße 8, 51147 Köln 02203-8990890		Year of construction - 1969 Number of schoolchildren – not specified Structural system – mixed, RC, masonry Vulnerability class - C
6	Gymnasium Thusneldastraße Thusneldastraße 17, 50679 Köln 0221 88791211		Year of construction - 1960s Number of schoolchildren - 843 Structural system – mixed, RC, masonry Vulnerability class - C
7	Gymnasium Kreuzgasse Vogelsanger Str. 1, 50672 Köln 0221 279710		Year of construction – not specified Number of schoolchildren - 979 Structural system - Vulnerability class - C

The last campaign took place in L'Aquila, Italy in May 2016. The investigated building was a part of the commercial school Instituto Tecnico Commerciale Luigi Rendina, which was considerably damaged during the Central Italy earthquake of 2009. With the support of the local civil protection authorities, the SIBYL work team gained access to the damaged building, which remains closed until the present time (Figure 10).

The on-site investigations provided valuable information for the development and testing of the approach as well as for practical aspects of its implementation. The results are documented both in the description of the approach and case studies.

Figure 10 Façade (left) and damaged interior (right) of the investigated school building in L'Aquila, Italy.

Considering the Greek test case, the AUTH made use of ambient noise measurements for the dynamic characterization of the building, deploying a denser network of stations equipped with 4.5 Hz three-component geophones, which have a better amplitude resolution and a lower internal noise than the MEMS included in the SOSEWIN system (precursor of the higher quality MPwise developed within this project).. The instrumentation layout included 38 CUBE[19] digitizers connected to the geophones, where the two horizontal components were oriented along the longitudinal and transversal directions of the buildings. GPS antennas guaranteed the time synchronizations among all instruments. Ambient noise was recorded simultaneously for about 20 hours in all stations with a sampling rate of 400 Hz. In order to capture the translational and torsional modes of the buildings, 4 sensors were installed at the corners of each floor close to the vertical structural elements (i.e., reinforced concrete columns).

Figure 11 Installation of the temporary network in the buildings of the AUTH campus (see Figure 9). These sensors are located close to the RC columns.

The flowchart shown in Figure 12 describes the different steps of the procedure for the evaluation of the seismic vulnerability of existing reinforced concrete (RC) buildings, which combines numerical analysis and field monitoring data. The recorded ambient noise measurements were used to derive the experimental modal model of the buildings and identify their modal properties based on operational modal analysis (OMA).

---

[19] https://www.gfz-potsdam.de/en/section/geophysical-deep-sounding/infrastructure/geophysical-instrument-pool-potsdam-gipp/instruments/seismic-pool/recorder-dss-cube3/

The modal identification results were used to update and better constrain the initial finite element (FE) models of the buildings, which were based on the design and construction documentation plans. Model updating aims at the "correction" or "update" of the initial FE model based on the processing of measurements made on the test structure. The main purpose was to iteratively update parameters to result in structural models that better reflect the measured data.

In the present methodology, a manual updating scheme ("trial and error") was proposed that considers only a limited number of parameters, allowing the observation of the process in order to gain a complete insight into the sensitivity of the structural behaviour to these parameters. The updating procedure consists of an eigenvalue sensitivity analysis of the elastic numerical modal models to identify the parameters that most influence the structural modes of interest, which are then used in the manual updating process to define the optimal analytical models. The selection of the best updated FE model of each building was made by evaluating an appropriate response correlation function between experimental and numerical results. Finally, three-dimensional nonlinear incremental dynamic analyses of the nonlinear updated models were performed in order to estimate the failure mechanism of the structure and derive the building-specific fragility functions.

Figure 13 compares the updated numerical and experimental modal models of the Administration building in terms of resonance periods and mode shapes, presenting also the resulting Modal Assurance Criterion (MAC[20]) values for the three first modes, which is used to evaluate the reliability of the results. MAC values higher than 0.8 or 0.9 describe an excellent matching of the derived model with the experimental results. The eigen frequencies and mode shapes of the updated FE model are compared to the initial ones as well as to the experimental results. It is seen that the updated model correlates well with the experimental results for all the modes under investigation (MAC>0.8).

For the updated model of the Administration building, nonlinear static pushover analysis, as well as three-dimensional incremental dynamic analyses, were performed to evaluate its seismic performance and to assess its vulnerability and associated fragility curves. To perform the nonlinear dynamic analysis of the building, a target spectrum for stiff soil conditions (V_{s30}=410 m/s computed from the site assessment survey conducted in the project, see below), corresponding to the normal seismic design scenario (i.e., expected ground motion with a return period of 475 years) and a suite of acceleration time histories were needed, representative of such a scenario. The target spectrum was defined based on the disaggregation of the probabilistic seismic hazard analysis (PSHA) results for the AUTH area. The fragility functions were derived for the immediate occupancy (IC) and the collapse prevention (CP) limit states in terms of peak ground acceleration (PGA). Figure 14 shows the derived building-specific fragility curves for the Administration building and a comparison with generic curves from the literature (Tsionis et al., 2011), which reflects the vulnerability of the most common typologies of similar RC buildings in Greece that have been designed according to low seismic code provisions. The comparison of the derived building-specific fragility curves with curves from the literature shows that the use of conventional generic curves, although appropriate for assessing vulnerability and losses at the regional/urban scale, may lead to inaccurate fragility and loss estimates in the case of individual building assessments, which constitute crucial components within the framework of decision making and risk mitigation strategies (e.g., seismic safety and rehabilitation costs).

---

[20] A statistical indicator, which provides a comparison method of estimates of modal vectors originating from different sources (Allemang and Brown, 1982).

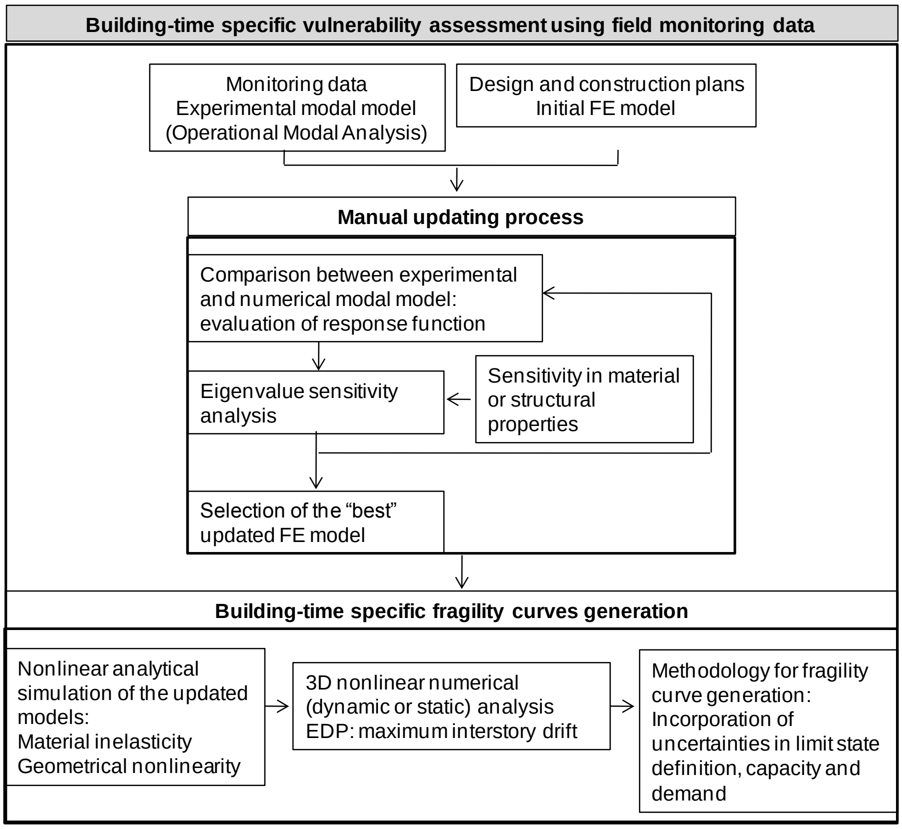


Figure 12 Methodological framework for the derivation of building – specific fragility curves for RC buildings.

For the updated model of the Faculty of Philosophy building, unfortunately, it was not possible within the available timeframe of the project to complete the vulnerability assessment procedure due to difficulties in the nonlinear modelling and analysis of the huge structure. Several nonlinear models were generated using different FE codes, however, numerical issues associated with the very large number of inelastic structural elements of the structure did not allow any nonlinear analysis. Further investigation is already in progress, with the aim of efficiently limiting the size of the model and at the same time realistically representing the structural and dynamic behaviour of the building.

To evaluate the dynamic characteristics of the buildings, namely the natural frequencies and mode shapes, system identification, OMA was again used. In order to verify and enhance the modal identification results, analyses have been conducted using both non-parametric and parametric identification techniques. Figure 15 shows representative eigen frequency and mode shape results of the identified modes for the Administration building. The building exhibits coupled sway and torsional modes in the frequency range of interest, which are expected in cases of geometric and structural irregularities or eccentricities between the centres of mass and of rigidity. The highly coupled obtained mode shapes reveal the complex vibrational characteristics of the building, especially for the first two identified frequencies. Although coupled, the predominant motion of the first mode is mainly along the transverse direction, whereas the second one is along the longitudinal direction. The modal identification results were used for the finite element updating of the buildings under study. A validated model of the building would help to check a simplified model with respect to its accuracy in describing dynamic characteristics of the building and, thus, to improve upon the SIBYL approach.

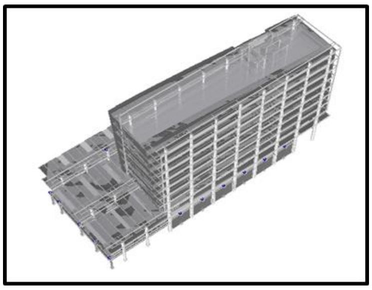
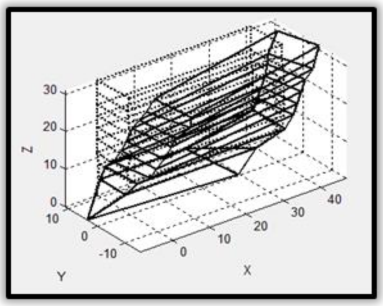
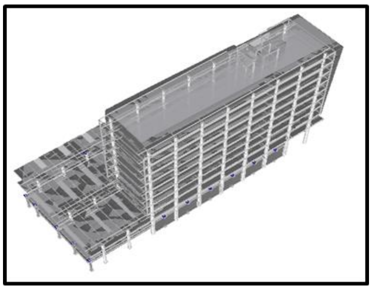
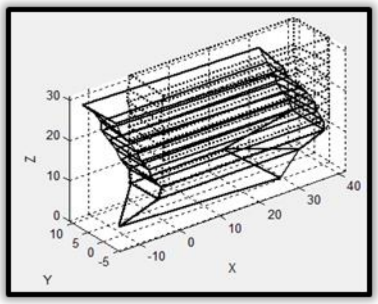
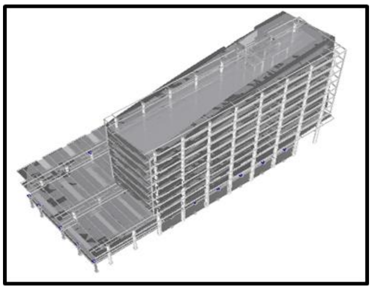
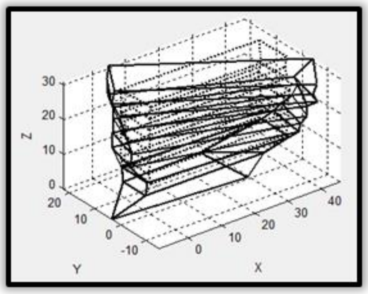
Initial FEM T (sec)/f (Hz)	**Mode shape of updated FEM T (sec)/f (Hz)**	**Mode shape of experimental model T (sec)/f (Hz)**	**MAC**
Coupled translational along the transverse direction T_1=1.08sec / f_1=0.93Hz			0.89
	T_1=1.09sec / f_1=0.92Hz	T_1=0.83sec / f_1=1.21Hz	
Coupled translational along the longitudinal direction T_2=0.96sec / f_2=1.04Hz			0.90
	T_2=0.96sec / f_1=1.04Hz	T_1=0.80sec / f_1=1.25Hz	
Torsional T_2=0.63sec / f_2=1.59Hz			0.87
	T_3=0.59sec / f_3=1.69Hz	T_3=0.59sec / f_3=1.69Hz	

Figure 13 Comparison of the updated finite element model of the Administration building and the experimental results (T: period, f: frequency).

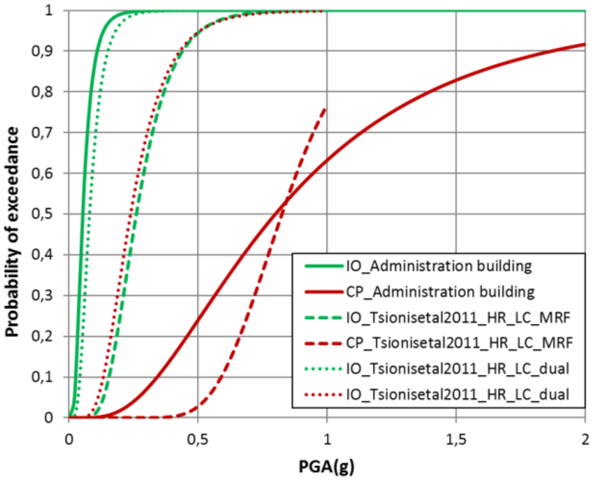


Figure 14 Comparative plot of the building-specific fragility curves derived for the Administration building with the corresponding fragility curves provided by Tsionis et al. (2011). HR-LC-MRF: high-rise, bare, low-code designed moment resisting frame; HR-LC-dual: high-rise, bare, low-code designed dual system.

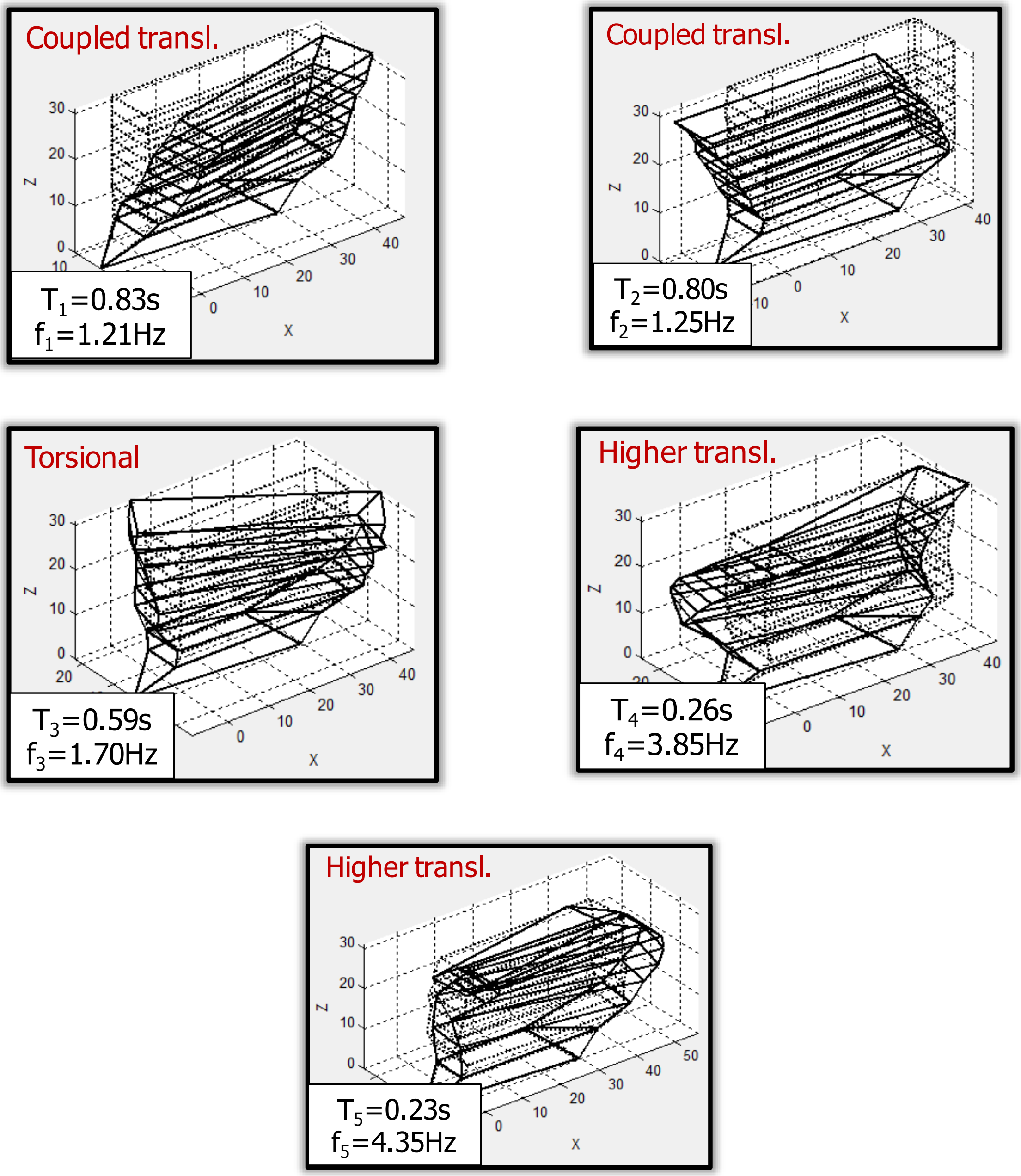


Figure 15 Eigen periods/eigen frequencies and mode shapes for the first five identified modes for the Administration building (T: period, f: frequency).

In parallel with these efforts by AUTH, TU-BERLIN endeavoured to develop a general procedure for building vulnerability assessment based on the simplified integral structural model (SISM). This process includes data collection, structural modelling and seismic evaluation. The approach also includes short-term monitoring of the building, implying short-term ambient vibration measurements. A considerable advantage of the SISM-based approach might be the fact that it does not require any sophisticated commercial FE software; instead, the computational procedure has been implemented in the Microsoft Excel software. There are obvious benefits, in particular, because this software is widely used and commonly available, while most engineers and specialists are already familiar with this application. This would also allow good opportunities for the training of CP practitioners and other potential users of this tool. To use the SISM-tool, the user generally does not require any special knowledge or experience, either in computer programming or in structural mechanics.

The developed computational procedure employs the displacement method of structural mechanics with specific group variables. The SISM of buildings consists of one integral beam element and one mass per floor (Figure 16).

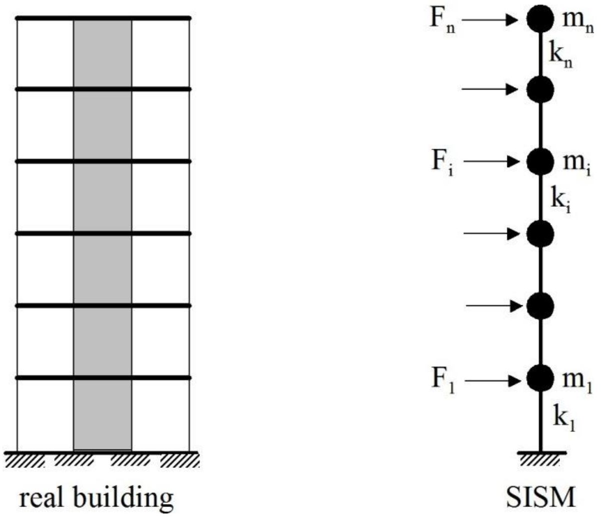


Figure 16 Modelling real buildings by simplified integral structural models (SISM) using one mass and stiffness per floor and direction.

The details of the developed approaches are described in the form of guidelines for the potential users in deliverable DC1. In particular, the guidelines describe the main input data required and sources of information, which may include: construction documentation (drawings and specifications), in-situ collected data (based on visual surveys, detail inspections, material testing) and simulated design (according to national practice, if no building-specific information available). DC1 additionally describes the computational algorithms and user actions required. Depending on the complexity of the investigated buildings, the amount and quality of the available information and the qualifications and experience of the practitioners, the total duration of the building assessment (including on-site data collection, data input in Excel and seismic evaluation) should not exceed one or two days per building.

The developed approach for individual vulnerability assessment of RC buildings with infill walls is implemented in form of conventional Microsoft Excel spreadsheets with macros, which are written using the programming language VBA (Visual Basic for Applications). Deliverable DC3 provides the user instructions for the input of structural data and the interpretation of the results of the assessment. No special knowledge in programming is required. The tool is suitable for civil engineers or trained technicians familiar with Excel. The time of self-training is estimated to be 1-2 days, and has already been tested by student participants.

An application of the SISM approach is shown below using as an example the Faculty of Philosophy building (Figure 9). On the basis of the collected geometry, material and structural data, the SISM model for the building was constructed for two planar directions separately. The torsional mode of vibration was not considered. Two corresponding calculated bending modes are shown in Figure 17. They match qualitatively well with the measured bending modes of the building. The calculated natural frequencies (f_{c1}=1.59 Hz, f_{c2}=1.71 Hz) are very comparable with the measured ones (f_{m1}=1.60 Hz, f_{m2}=1.72 Hz).

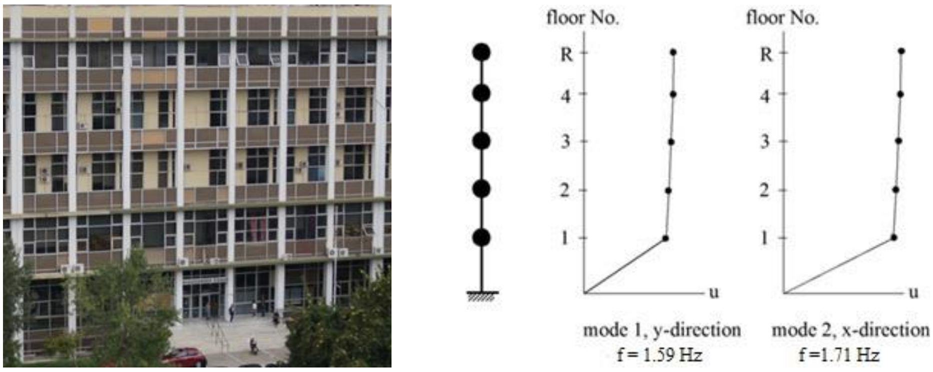
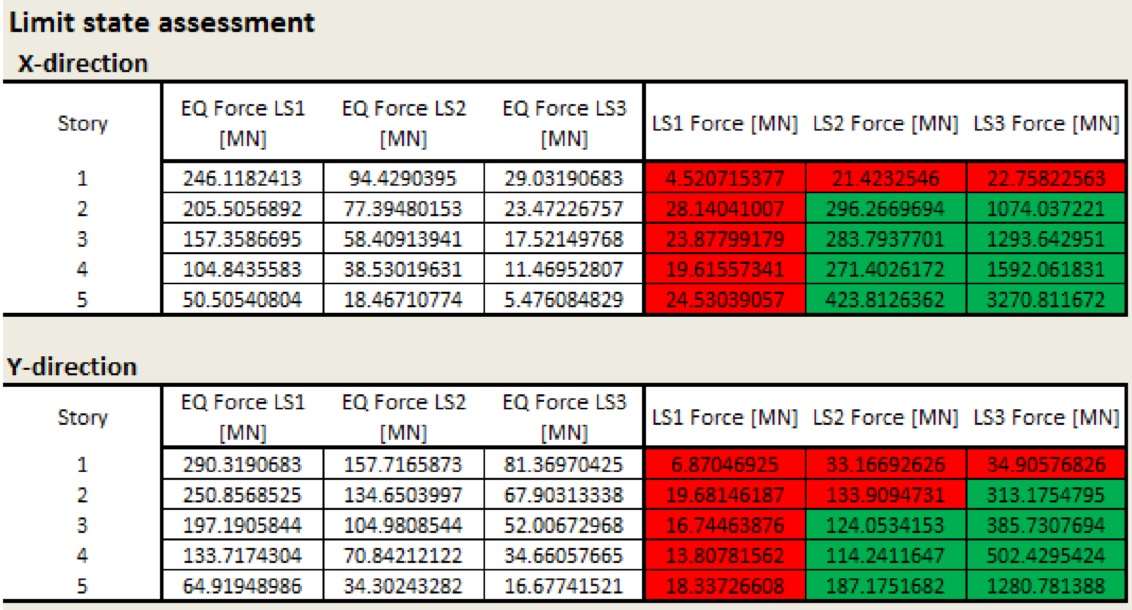


Figure 17 Central part of the Faculty of Philosophy building (left), the SISM and its first bending modes (right).

An interesting feature about this building has been detected. In contrast to the original design documentation, the current building has one additional floor due to a structural modification made 20 years after the original construction. The measured new total height of the building is about 5 m greater in comparison with the height specified in the design drawings. Furthermore, sample measurements of the cross-sectional dimensions of columns showed considerable changes in comparison with the original data. Obviously, such essential structural modifications would considerably change the vibration properties of the building and thus influence its seismic vulnerability. This fact emphasizes the crucial importance of in-situ inspections for the assessment of the actual structural vulnerability of existing buildings.

In that particular case, we only used the information collected on site, which was quite limited. The numerical results obtained by the use of the SISM-based approach and the Excel tool (

Figure 18) show that the limit state LS3 (failure of the structure) could be expected in the ground floor of the building for the given level of seismic hazard (red), while the upper floors perform much better (green). The main reason for the building´s fragility is the so-called “soft story” in the ground floor. The former Greek seismic design rules, like similar rules in several countries in Europe, were incapable in the 1960s to eliminate such structural deficiencies.



Limit state assessment

X-direction

Story	EQ Force LS1 [MN]	EQ Force LS2 [MN]	EQ Force LS3 [MN]	LS1 Force [MN]	LS2 Force [MN]	LS3 Force [MN]
1	246.1182413	94.4290395	29.03190683	4.520715377	21.4232546	22.75822563
2	205.5056892	77.39480153	23.47226757	28.14041007	296.2669694	1074.037221
3	157.3586695	58.40913941	17.52149768	23.87799179	283.7937701	1293.642951
4	104.8435583	38.53019631	11.46952807	19.61557341	271.4026172	1592.061831
5	50.50540804	18.46710774	5.476084829	24.53039057	423.8126362	3270.811672

Y-direction

Story	EQ Force LS1 [MN]	EQ Force LS2 [MN]	EQ Force LS3 [MN]	LS1 Force [MN]	LS2 Force [MN]	LS3 Force [MN]
1	290.3190683	157.7165873	81.36970425	6.87046925	33.16692626	34.90576826
2	250.8568525	134.6503997	67.90313338	19.68146187	133.9094731	313.1754795
3	197.1905844	104.9808544	52.00672968	16.74463876	124.0534153	385.7307694
4	133.7174304	70.84212122	34.66057665	13.80781562	114.2411647	502.4295424
5	64.91948986	34.30243282	16.67741521	18.33726608	187.1751682	1280.781388

Figure 18 Results of the building assessment of the Faculty of Philosophy building, AUTH, from the use of the SISM-Tool.

During the same time as the building monitoring, a temporary 2D array of 38 stations was established outside, between the two buildings, as shown in Figure 19, for a site assessment. As with the buildings, each station consisted of a 4.5Hz three-component geophone coupled to a CUBE digitizer and a GPS receiver. The scope of these measurements was to determine the shear-wave velocity and the site response characteristics of the foundation soil. The shear-wave velocities are used to classify the foundation soil into EC8 soil categories and subsequently for the numerical and structural modelling of the two buildings. In addition, the Vs velocities will be used for the definition of the reference input motion acceleration spectrum to be used as input motion for the dynamic analyses of the buildings.

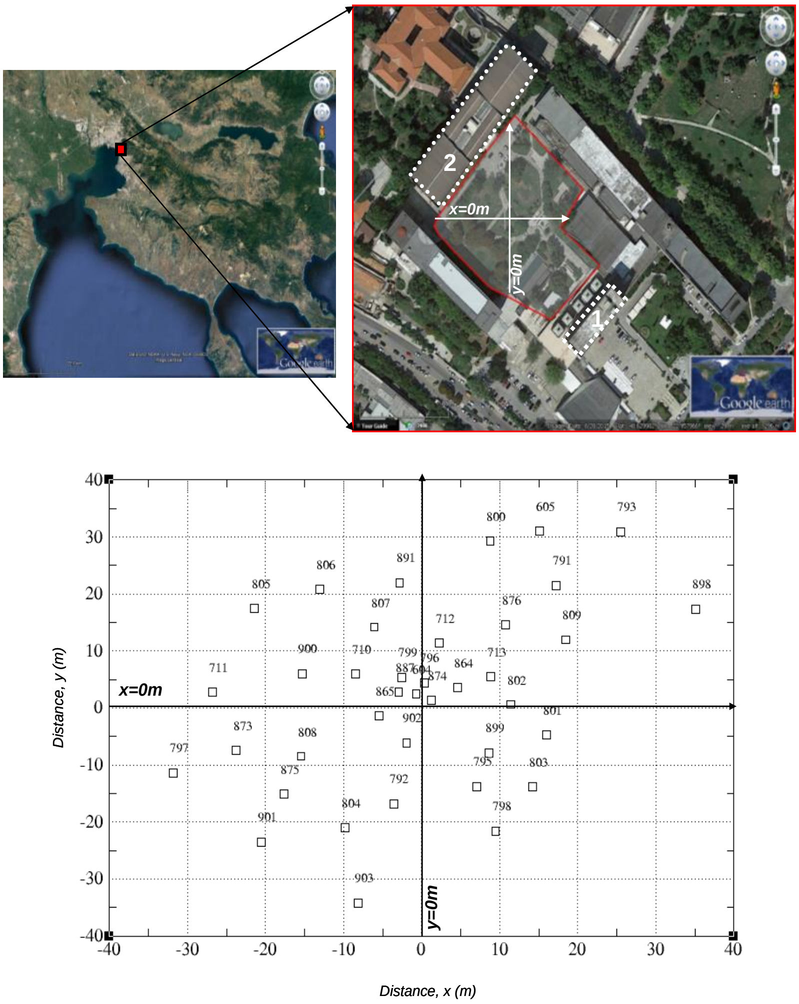


Figure 19 (Top) The location of the 2D array within the AUTH campus (red polygon) and (bottom) the spatial distribution (squares) of the 38 stations. The numbers indicate the code of each station. Numbers 1 and 2 in the map correspond to Administration and Faculty of Philosophy buildings, respectively (see Figure 9).

Using only the vertical component of the noise recordings and the SPatial Autocorrelation Coefficient - SPAC method (Aki, 1957), the cross correlation coefficients of the 703 available station pairs were calculated. The phase velocity values as a function of frequency were determined by inverting these correlation coefficients, as shown in Figure 20, together with the inferred 1D shear-wave velocity profile for the site. The foundation soil of the two buildings consists of a stiff stratum about 20 m thick, characterized by Vs velocities greater than 400-500 m/sec, underlying a thin layer (8-9 m) of lower velocity surface materials, leading to the soil conditions in the investigated site being classified as soil type B according to the current EC8 code. The stiffness of the foundation soil is also confirmed by the results of the H/V method (Nakamura, 1989), which determined the resonant frequency of the foundation soil to be between 2.2 Hz to 2.7 Hz (Figure 21). The theoretical 1D response of the shear wave velocity profile determined by the SPAC method is in good agreement (in terms of resonance frequency) with the experimental H/V ratios, confirming the accuracy of the inferred 1D velocity profile.

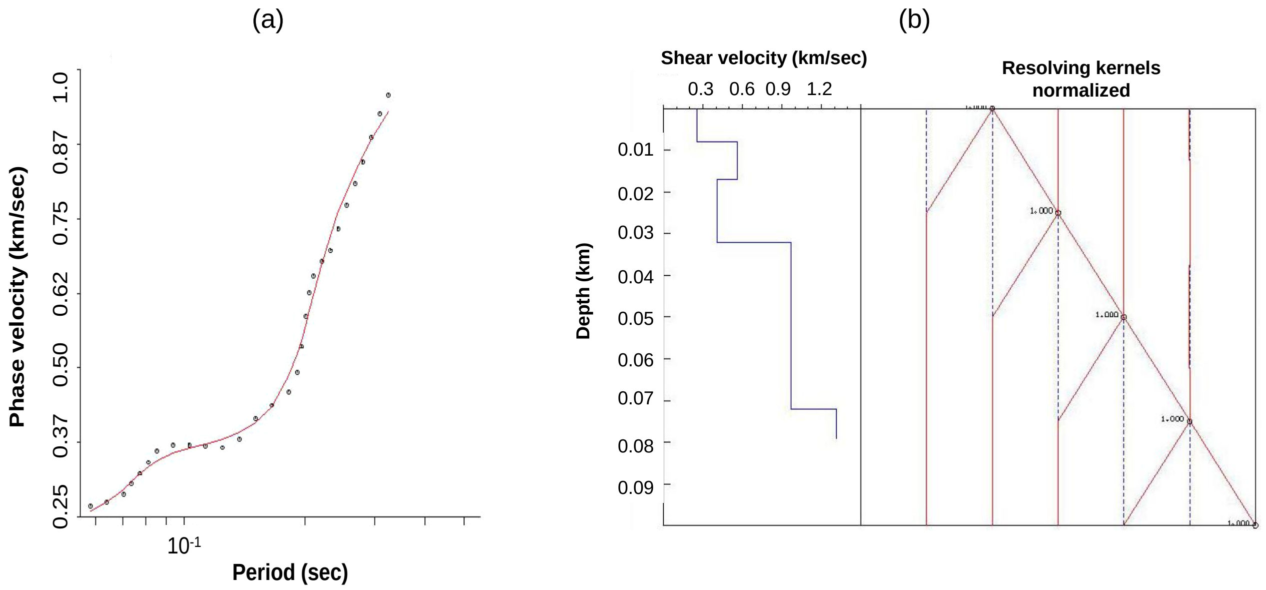


Figure 20 a) The circles show the final estimate of the phase velocity dispersion curve, while the solid line shows the predicted dispersion curve computed for the best-fitting model through the inversion procedure. b) The shear-wave velocity profile obtained from the inversion of the dispersion curve (a), together with the resolving kernels for each layer in the model.

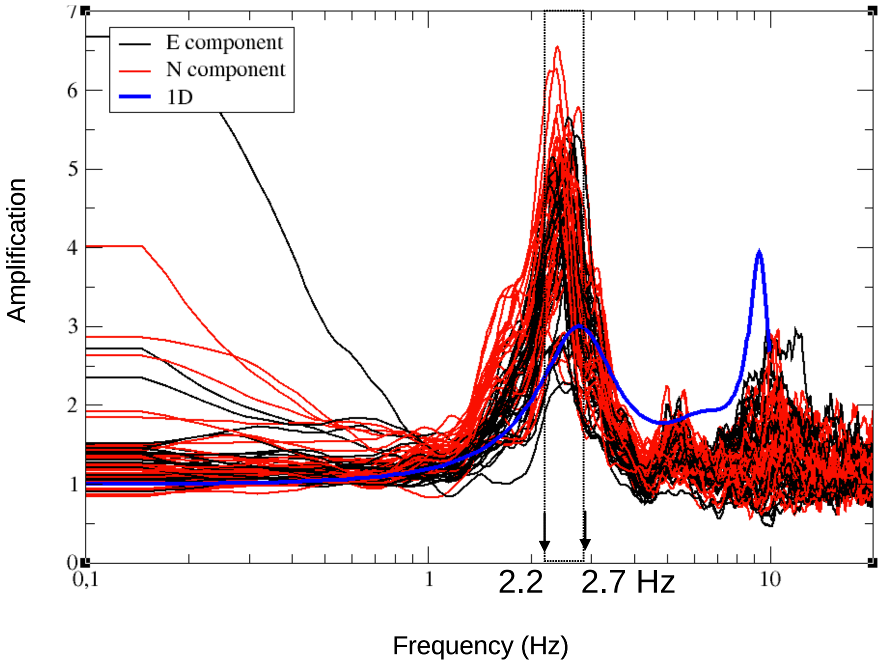
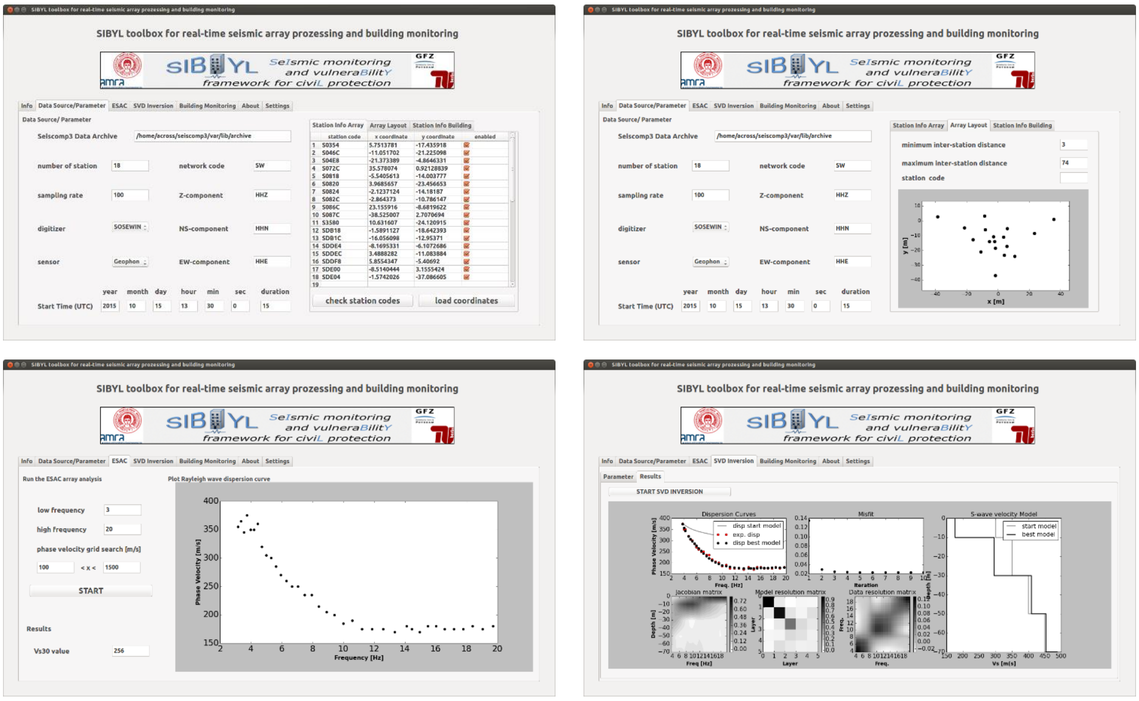


Figure 21 Average H/V ratios of the two horizontal components for the 38 stations used in the 2D array and 1D theoretical transfer function calculated from the Vs profile of Figure 20.

Site assessments were also undertaken in the vicinity of the schools surveyed during the Cologne activities. This involved setting up arrays either within the school itself (e.g., playground, assembly area) or just outside. The MPwise units were employed in these site assessments, and preliminary estimates of the site conditions were made using the software installed on these systems (see Figure 22). The arrays consisted of 10 MPwise units connected to 4.5 Hz geophones. The sampling rate was set to 400 samples per second (Nyquist at 200 Hz). The ESAC method (e.g., Parolai et al., 2006) was applied to derive the dispersion curves for Rayleigh waves. The dispersion curve can provide the necessary information for S-wave velocity estimation. Applying the method proposed by Albarello and Gargani (2010), the so-called V_{S30} parameter, a commonly used proxy that provides a measure of potential site amplification (Borcherdt, 1994), was estimated at each of the 7 different locations. Albarello and Gargani (2010) estimated the uncertainties associated with these values to be of the order of 10%. Picozzi and Albarello (2007) showed that in cases where the obtained final S-wave velocity model lies close to the global minimum of the solution, a linear inversion can be carried out to refine these models. Here, we take advantage of the linearization of the problem to study how the procedure and data can be reliably constrained through the analysis of the model and data resolution matrices (see Figure 22). In particular, we also implemented a simple procedure that allows the linear inversion to be started from a model close to the "real one", therefore permitting the use of a rapid linear inversion.

Guidelines on the undertaking of such assessments, the analysis and interpretation of the results are presented in deliverable DC2.



Data Source/ Parameter
Seiscomp3 Data Archive: /home/across/seiscomp3/var/lib/archive
number of station: 18
network code: SW
sampling rate: 100
Z-component: HHZ
digitizer: SOSEWIN
NS-component: HHN
sensor: Geophon
EW-component: HHE
Start Time (UTC): year 2015, month 10, day 15, hour 13, min 30, sec 0, duration 15

	station code	x coordinate	y coordinate	enabled
1	S0354	5.7513781	-17.435918	☑
2	S046C	-11.051702	-21.225098	☑
3	S04E8	-21.373389	-4.8646331	☑
4	S072C	35.578074	0.92128839	☑
5	S0818	-5.5405613	-14.003777	☑
6	S0820	3.9685657	-23.456653	☑
7	S0824	-2.1237124	-14.18187	☑
8	S082C	-2.864373	-10.786147	☑
9	S086C	23.155916	-8.6819622	☑
10	S087C	-38.525007	2.7070694	☑
11	S3580	10.631607	-24.120915	☑
12	SDB18	-1.5891127	-18.642393	☑
13	SDB1C	-16.056098	-12.95371	☑
14	SDDE4	-8.1695331	-6.1072686	☑
15	SDDEC	3.4888282	-11.083884	☑
16	SDDF8	5.8554347	-5.40692	☑
17	SDE00	-8.5140444	3.1555424	☑
18	SDE04	-1.5742026	-37.086605	☑
19				

minimum inter-station distance: 3
maximum inter-station distance: 74
station code:

Run the ESAC array analysis
low frequency: 3
high frequency: 20
phase velocity grid search [m/s]: 100 < x < 1500
Results
Vs30 value: 256

Figure 22 MPwise output from processing seismic array data for site assessment (note, this is the Graphical User Interface (GUI) developed for the MPwise within SIBYL). Top left) The data source and parameter menu allows the user to configure different parameters, such as the number of stations, network code, sampling rate, channel identifier, digitizer and sensor specific constants. Top right) Overview of the array geometry. Bottom left) Real-time processing of the array measurements using the ESAC method to obtain a Rayleigh wave dispersion curve. Bottom right) SVD (Single Value Decomposition) inversion to obtain a 1D shear wave velocity model, as well as a quality control provided by Jacobian, model and data resolution matrices.

In conclusion for this Task, approaches for building vulnerability assessment have been developed, implemented and tested on several buildings in Greece, Germany and Italy, in full agreement with the original plan. In addition to the original plan, this approach is now applicable even in the case where if no preliminary information is available on the building. The three case studies are described in detail in deliverable DC4. As the principal goal of the SIBYL work groups was the development of a practice-oriented methodological framework for the end-users, including in-situ data collection, structural modelling and building assessment, DC4 provides a description of the full spectrum of the investigation steps, data collected on site and results obtained for the selected buildings. It therefore may serve as a data-filled instruction manual for potential users.

Task D "Real-time monitoring during a seismic sequence"

The deliverable for this task was DD1 "Guidelines for the assessment of time-variant seismic risk of monitored single structures". The expected results of the task were: i) algorithms for early warning systems that account for cumulative damage during seismic sequences; ii) algorithms for the implementation of building tagging in structural monitoring systems; and iii) closed-form models for the assessment of time-variant seismic risk over the short-time scales (during the aftershock sequences). All algorithms and models were rigorously developed and the DD1 deliverable has been published (Iervolino et al., 2015).

The main objective of the research was to investigate the possibility of assessing structural seismic risk for individual buildings while accounting for two main sources of time-variability, namely the hazard and the structural vulnerability. Regarding the hazard, in the classical engineering approach, the expected number of seismic event within a unit period of time is constant (i.e., the earthquake rate). This is because the time scale of analysis is the life span of the structure and the so-called mainshocks are the considered seismic threat. Mathematically, this allows the use of the *homogeneous* Poisson process to count the earthquakes' occurrences. On the other hand, when aftershocks effects have to be considered (i.e., during seismic sequences), the rate of occurrence or exceedance of a given ground motion intensity measure (IM) at the site of the structure is not constant over time and counting models have to be time-variant; e.g., the non-homogeneous Poisson process.

On the structural side, the traditional approach to performance based earthquake engineering (PBEE) assumes that structural vulnerability is constant over time (the structure is instantaneously repaired after each damaging event). This hypothesis may be strong in some particular applications (e.g., risk assessment during seismic swarms) and has been removed in this work. It is now considered that the structural vulnerability may change due to the effect of continuous damage (e.g., aging) or due to instantaneous shocks (e.g., earthquakes). In other words, it is assumed that the attainment of a certain damage level (e.g., failure) may also be produced by multiple partially-damaging seismic shocks, and not only in a single catastrophic event, as implicitly assumed in the *fragility* functions employed in PBEE. The approach followed in this work involves modelling state-dependent vulnerability; i.e., modelling the probability of transition, in one event, between progressively worse damage states, given the state of the structure prior to the event. Indeed, if one is able to adjust the structural vulnerability as a function of the actual condition of the structure (i.e., the level of current damage or deterioration), it is then possible to probabilistically predict the behaviour of the already-damaged structure. This, although leading to a more elaborated formulation/calibration of the resulting models, enables one to describe forms of stochastic dependence among damage increments. In fact, if a probabilistic description of the occurrence of shock exists (as happens in PSHA), in conjunction with state-dependent vulnerability, one is able to probabilistically predict, in closed-form, the path of the structure from having an as-new condition to collapse, via multiple state-changing earthquakes.

A reliable solution of this type was derived during SIBYL based on modelling the damage process via a Markov chain (i.e., a discrete-time and discrete-state Markovian process). The time *t* is discretized in intervals of fixed width equal to Δ, which may be considered to be the time unit (e.g., one year), $\Delta = 1$. The domain of the considered damage index (structural performance measure) is partitioned to have a finite number (*n*) of damage states (DS). The various $DS_i, i = \{1, 2, \ldots, n\}$, are factually limit states, identifying intervals of the damage metric considered between as-built conditions and failure, that the structure has to progress through (not necessarily one-by-one) to reach collapse (Figure 23). The estimation of the transition probabilities may require significant computational effort, but has to be done only once. Two alternative procedures for the estimation of such probabilities are described in deliverable DD1.

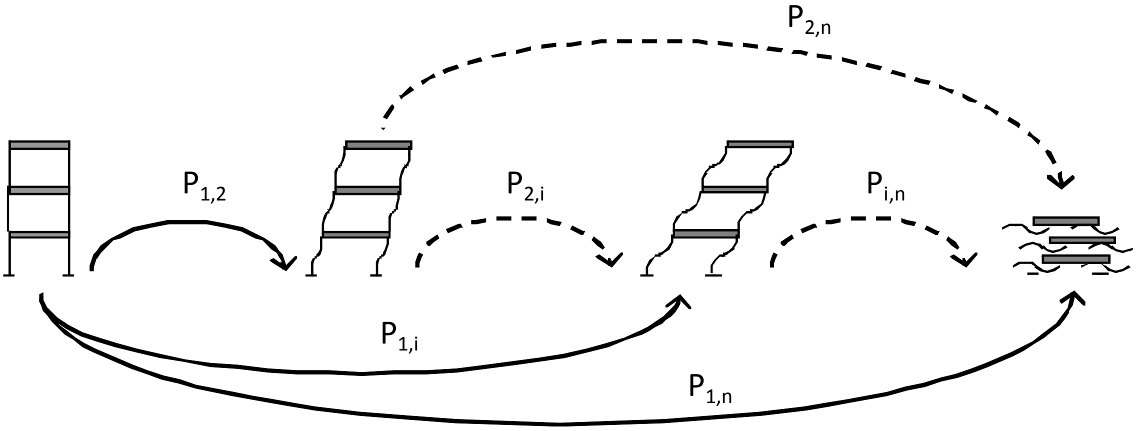


Figure 23 Sketch of the discretization of the degradation states of a damage-accumulating structure, proceeding from as-built (far left) to collapse (far right). $P_{i,j}$ refers to the transition probability between damage state i to damage state j, given the occurrence of an earthquake.

Knowing the transition probability matrix, $P_{i,j}$, and following this framework, it is possible to compute the probability that the structure will reach any damage state within any time interval of interest. Defining a threshold of tolerable risk in the considered time window, it is possible to define an automatic procedure of building tagging in order to control the accessibility to the building.

An illustrative plot summarizing such a procedure is shown in Figure 24. Let us assume that a mainshock occurred at time $t = 0$ and damaged a structure of interest. Let us also assume that, it is known that right after the mainshock, the structure is in an Immediate Occurrence (IO) damage state: this information can be derived, for example, by a structural health monitoring system or by an inspection of the structure (however, the building tagging works also if the structural damage is unknown). In the figure, t is the time since the mainshock and it is plotted against the probability of failure (damage state equal to or higher that the Life Safety, LS) within one week. Thus, arbitrarily assuming the probability 1% as a tolerable collapse risk over 1 week during an aftershock sequence and 10 times its value as a tolerable risk for emergency operations, it may be said that before the decaying risk intersects the largest probability, the structures is red tagged (i.e., cannot be accessed) for the next week, is green tagged after the risk decreases to below 1%, and can be entered only by trained agents in between. It is worth noting that if another earthquake occurs, the structural damage state and the information about seismicity may change. New information can therefore be accounted for in this framework and a new evolution of failure probability can be automatically computed.

Furthermore, this algorithm for risk computation can be implemented in the MPwise system and therefore be tested under real-time conditions. The implementation phase is ongoing and in the future the testing phase at different test sites in Europe and Central Asia (the latter in association with other projects) as part of decentralized onsite earthquake early warning networks will follow.

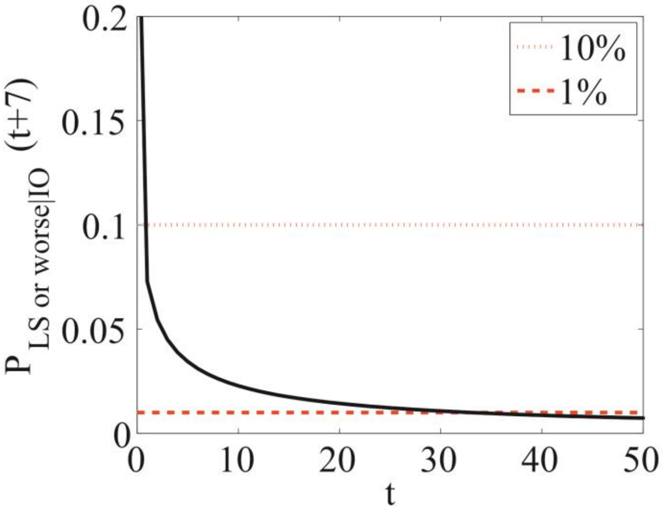


Figure 24 Failure probability (where 10% and 1% are considered thresholds) in the 7 days following *t* given survival at *t*, and the possible occurrence of damaging aftershocks (mainshock occurred at *t*=0).

Task E “Training and capacity building”

The ultimate goal of the SIBYL project is that the developed tools and framework will be employed by CP authorities and other interested parties to mitigate against earthquake disasters. There is also the basic concern that the resulting products should be easily used by technical personnel without the need for extensive training and a variety of backgrounds. Some deliverables consider this by presenting various guidelines in the use of the developed tools or for general best practice. The materials for this are summarized in deliverable DE1 “Training materials for the use of the developed framework and tools” where the deliverables that serve as guidelines are listed, a website where an interested practitioner can gain access to the tools required for the satellite and in in situ image analysis[21], as well as the contact details for the persons specifically for each subset of tools.

In addition, while the focus of the SIBYL work was to contribute to the improvement of seismic hazard and risk assessment, there is the intention that the tools and methods developed would need to be able to be transferred/adapted to other hazard types. Such an attitude is necessary, given the growing attention being paid to multi-hazard and risk environments, for example, the Sendai Framework for Disaster Risk Reduction[22]. The tools and framework developed within SIBYL are believed to be adaptable to a multi-hazard and risk framework. This is partly due to the modular nature of the framework and tools, where each specific aspect can be expanded and/or tailored to the case at hand, for example, extending the capacity of the remote rapid visual screening (RRVS) tool (see deliverable DB3 “Guidelines of the mobile mapping system and remote visual screening”) to include typologies relevant to multiple hazards.

The expansion of the SIBYL products to a multi-hazard and risk environment would need to be centred on three aspects of the current framework:

- Data collection and monitoring. This in turn must be considered within three components.
  - *Remote sensing and mobile mapping tools.* This requires the remote sensing tools (i.e., the developed analysis tools and plugins) to be adapted to more than one hazard, while the mobile mapping tools will essentially see the RRVS expanded to allow an operator to include other parameters/structural characteristics than is currently allowed in the system. This therefore will require the including of other hazard dependent taxonomies.
  - *MPwise units.* The issue here is a matter of including within the MPwise units the capacity to record and process each (and preferably several) data streams appropriate for the hazard(s) at hand, e.g., ground motion for earthquakes, pore pressure for earthen dyke monitoring, temperature, etc.. Conceptually, this would not be a problem, with the need for current units to be upgraded to more powerful processing units and memory being comparatively simple given advances and diminishing costs in computer hardware.
  - *In-situ/detailed observations.* Again, this is a case of expanding/modifying what the inspectors are looking for. Follow-on projects, for example, could call upon as examples products such as the Inventory Data Collection Tool (IDCT)[23] developed by the Global Earthquake Model foundation[24], but

---

[21] https://github.com/GFZ-Centre-for-Early-Warning/REM_satex_plugin
[22] http://www.unisdr.org/we/coordinate/sendai-framework
[23] https://www.globalquakemodel.org/what/physical-integrated-risk/inventory-capture-tools/
[24] https://www.globalquakemodel.org/

which could conceivably have the capacity to include the inclusion of information relevant to other hazards. This, however, brings up the issue of having products that allow non-specialists to exploit them, although tools such as IDCT have this in mind.

- Fragility and vulnerability curves. An immediate example here is the use of the SISM (Task C) model for buildings exploited within this work to be applied to wind storms.
- Risk assessment. Risk assessment within a multi-hazard and risk environment requires its 3 components (hazard, exposure or elements at risk, and vulnerability or fragility) to be defined for each hazard type and the risk (in whatever form. i.e., buildings, infrastructure, population, etc.) can then be found in a straightforward manner. However, for a truly multi-hazard environment, there will be the need to consider interaction among hazards and risk elements, which would need more advanced methodological approaches (as developed, for example, in past projects like MATRIX[25] (New Multi-Hazard and Multi-Risk Assessment Methods for Europe) and STRESS[26] (Harmonized approach to stress tests for critical infrastructures against natural hazards).

Details of this discussion are presented in deliverable DE2 “Report on the potential for the developed system to be transferred to other hazard types”.

---

[25] http://matrix.gpi.kit.edu/index.php

[26] http://www.strest-eu.org/opencms/opencms/

Task F “Task publicity”

The publicity actions throughout the project were intended to:

- Disseminate knowledge about the aims and resulting products of the SIBYL project to the relevant communities, in particular CP authorities;
- Involvement of technical and professional communities in the actual development of the products;
- Transfer of knowledge and lessons learned from previous events and research projects;
- Demonstration activities (exploratory applications of the tools and methods);
- Contribute to informing the wider community in some of the issues surrounding seismic hazard and risk and what is being done to mitigate against them.

The actions undertaken and the response are reported in four deliverables: DF1 “Project website”, DF2 “Detailed plan for project publicity”, DF3 “Report on public outreach events/activities” and DF4 “Report on technical and professional outreach”, of which the latter two review all actions undertaken.

One of the most important dissemination tools is the project web-site. Its usefulness arises from it being often the first contact one has with the project’s outline, goals and results. It allows, for example, CP authorities to gain some insight into the state of the art of disaster risk reduction, while also informing other interested parties. The website (see Figure 25) is expected to remain active for two years. This is essential to ensure or at least assist in the lasting legacy of the project and its products. It will be essential to keep it up to date, which has generally been the case, hence additional, more recent, material will be added. This will be done in the coming weeks since the final deliverables and products are completed. We will include in the website (after appropriate permission from the individual partners and EC-ECHO is received) the deliverables themselves, as well as links to the various publications and theses that are being/have been produced using the outcomes of the project.

The Aims of SYBIL

SIBYL's aim is to develop an operational framework for Civil Protection (CP) authorities to rapidly an cost-effectively assess the seismic vulnerability of the built environment.

Such a framework will advise CP authoribes as to the most appropriate preventative actions for cases where:

- There is a need for short-notice vulnerability assessment in a pre-event situation
- For the monitoring of the build environment's dynamic vulnerability during a seismic sequence.

Helmholtz Centre Potsdam
GFZ German Research Centre
for Geosciences

Prof. Stefano Parolai
(Coordinator)
Helmholtzstraße 7
14467 Potsdam

Fon: +49 331 288-1290

stefano.parolai(at)gfz-potsdam.de
www.gfz-potsdam.de

EC ECHO **Kick-off-meeting** (Brussels, Belgium, **20.01.2015**)

Preliminary planning and technical **meeting** (Potsdam, Germany, **28.01.2015**)

Report pdf

Mid-term meeting Thessaloniki, Greece, 15th to 16th February 2016

Report pdf

Civil Protection Workshop L'Aquila, Italy, 30-31 May 2016

Report pdf

Final meeting (Potsdam, Germany, December, 2016)

Real-time tool developed

Field Work in Thessaloniki

Field Work in Cologne

User login

Enter your username and password here in order to log in on the website:

Username:

Password:

Figure 25 The SIBYL homepage with list of events, news and access to different sections of the website.

Interactions with the CP authorities came about via several avenues. These included project meetings (representatives of CP attended the first technical, mid-term and final meetings), field campaigns (in particular in Cologne and l’Aquila) and at other occasions that allowed the demonstration of the capacity of the framework and its components. The aim of their involvement was to provide recommendations on the needs of Civil Protection authorities and to gather feedback on the developed tools and their potential expansion.

Interactions with CP authorities assisted the consortium during the course of the project to better understand their needs. For example, representatives of THW discussed which of the project´s products would be most useful to them. In this case, mobile camera system was of great interest, while the site assessment methods do not appear to be of great benefit to their needs (discussion with Mr. Marius Halbach of THW during field work in Cologne, November, 2016), although its value to the overall scheme of hazard and risk assessment was still acknowledged. Another example was during the final project meeting (Potsdam, December 2016) where a representative of BBK (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe[27]) outlined a clearer picture of the role of BBK, in which, while they themselves may not be the most appropriate avenue for the SIBYL products, those parties to whom the consortium should communicate within the context of future activities in order to better direct research actions were presented.

Furthermore, a number of technical papers, presentations and theses were produced/in preparation, as outlined in Table 2. It should be emphasised, however, that projects such as SIBYL will continue to provide material for academic and technical presentations long after it has been completed and all reports finalised.

Other activities include:

- Prof. Pitilakis (AUTH) took part in several high level meetings where the goals of SIBYL were presented.
    - Meeting of the European Committee of Normalisation for the revision of Eurocode 8 (Paris, France March 2016), where topics related to the objectives and output of SIBYL should be taken into consideration.
    - Meeting with EC officers (H2020) regarding future calls (Brussels, Belgium, March, 2016) where a project following-on from SIBYL could be submitted.
- During the field work, interactions with the general public took place, in particular during the field activities in Cologne. Here, discussions were held with school principles on the aims and expected outcomes of the project, while teachers and students showed an interest in our activities (Figure 26). Furthermore, the authorities concerned with the safety of schools were contacted prior to this field work and were interested in being kept in formed.

---

[27] http://www.bbk.bund.de/DE/Home/home_node.html

Table 2 List of publications, presentations and other technical works produced within the context of the SIBYL project (see deliverable DF4).

Authors	Title	Journal or Conference
Iervolino I., Giorgio M, Chioccarelli E.	Markovian modelling of seismic damage accumulation	Earthquake Engineering and Structural Dynamics, 2015, 45:441-461, doi: 10.1002/eqe.2668
Tyagunov S., Petryna Y.	In-situ data collection for structural modelling and assessing seismic vulnerability of existing buildings. International Workshop "New advances in seismic risk assessment and disaster mitigation"	May 23-24, 2016, Tashkent, Uzbekistan
Tyagunov S., Petryna Y.	An operational framework for rapid and low-cost vulnerability assessment of existing building stock in seismic areas.	1st International Conference on Natural Hazards and Infrastructure: Protection, Design, Rehabilitation, 28-30 June 2016. Chania, Greece. Paper 126.
Tyagunov S., Petryna Y.	Structural Health Monitoring and Vulnerability Assessment of Buildings in Earthquake Prone Areas.	8th European Workshop on Structural Health Monitoring (EWSHM), 5-8 July 2016, Bilbao, Spain. Paper 410, 10 pp.
Tyagunov, S., Petryna, Y.	Seismic Vulnerability Assessment of Existing Buildings. International Conference "Actual Problems in Modern Seismology".	12-14 October, 2016, Tashkent, Uzbekistan
Petryna, Y.; Mostböck, A.; Bindi, D.; Petrovic, B.:	Dynamische Vor-Ort-Untersuchungen an typischen Gebäuden in Zentralasien.	In: Verein Deutscher Ingenieure (Hrsg.) 5. VDI-Fachtagung Baudynamik 2015. 2244. Düsseldorf: VDI-Verlag, 2015, S. 527-542; ISBN/ISSN 978-3-18-092244-7
Fleming, K., Parolai, S., Iervolino, I., Pitilakis, K. and Petryna, Y.	The SeIsmic monitoring and vulneraBilitY framework for civiL protection (SIBYL) Project: An overview and preliminary results	EGU General Assembly 2016, held 17-22 April, 2016 in Vienna Austria
Pittore, M., Boxberger, T., Fleming, K. and Parolai, S.	On the application of rapid environmental mapping methodologies (REM) to seismic risk understanding and vulnerability monitoring	41st IAHS World Congress "Sustainability and Innovation for the Future", 13-16th September, 2016, Albufeira, Algarve, Portugal.
TU-BERLIN, Education	Materials of the project were included in specific lectures for students in Bachelor and Master Courses at TU Berlin.	
TU-BERLIN, Education	10 Bachelor and Master Theses and Student Projects were based on the SIBYL topic and materials of the project.	
AUTH, Education	2 Master theses were based on the SIBYL project.	
Karapetrou S., Fotopoulou S., Manakou M., Thomaidis I., Yfantidou E., Pitilakis K.	Building-specific vulnerability assessment of RC buildings using short term field monitoring data	In preparation
Boxberger, T., Fleming, K., Pittore, M., Parolai, M., Pilz, M. and Mikulla, S.	The Multi-Parameter wireless sensing system (MPwise): description and application	In preparation

Figure 26 Some of the interactions with the general public during the SIBYL project. (top left) The team and the principle of the Humboldt-Gymnasium, Dr. Harald Junge. (top right) The team with Mr. Marius Halbach of THW. (bottom) Often teachers and students showed an interest in the activities of the assessment teams.

Follow-up

CP authorities generally showed a great interest in the results of the SIBYL project. However, the structure, the assignment and the responsibility of the CP authorities in Greece, Germany and Italy are quite different. Therefore, a direct application of the developed tools in the same way is probably difficult for all participating countries without proper adaptation to the specific features, structure and capacities of each entity. Understanding these differences is hence of major importance for the approval of the developed tools and the relevant permission aspects for operation. Joint test activities between the SIBYL consortium and CP authorities in a future implementation project have to be done before any developed tools gain permission or are accepted for practical or operational application. Another stakeholder that should be contacted for future projects would be the Emergency Response Coordination Centre[28] of EC-ECHO, who role is to support the more improved coordination and response to disasters, and who provide such information as preliminary damage maps which could be incorporated into such tools as the REM.

Another difficulty concerns the responsibility of CP authorities. THW and BBK in Germany are federal agencies that can give general recommendations. Their operations can be ordered only by the states, municipal or private owners of the building stock, who are actually responsible for the safety of the buildings. Therefore, the application of the SIBYL tools must be made for the public and for a huge number of local stakeholders in the future. Similar problems, i.e., allocation of responsibility, are encountered in other EU countries, namely Greece and Italy. Consequently, the adaptation of the SIBYL methods and tools to the specific requirements of each country is deemed necessary and should be a concern of the future projects.

In terms of the next steps within a more technical context, one of the major challenges will be to adapt or expand the SIBYL tools and framework for a multi-hazard and risk environment, as outlined in the Task E report. This may be seen in two ways. The first, a relatively simple task, is to expand the framework to be able to accommodate other hazard types. As mentioned in the report (Task F), for example, extending the fragility curves from seismic to wind is feasible, while the GFZ-MOMA and RRVS can be, with comparative ease, can be adapted to allow hazard specific parameters to be identified. The second point, however, is that for a truly multi-hazard and risk tool, the interactions that may arise (and potentially enhance) between hazard and risk types, e.g., cascading events, and even the order in which a sequence of events may occur, will need to be accommodated and would therefore require considerably more effort.

---

[28] http://ec.europa.eu/echo/node/402

References

Abraham, T. and Roddick, F.J. (1999) Survey of Spatio-Temporal Databases, *GeoInformatica*, 3(1), 61–99.

Allemang, R.J. and Brown, D.L. (1982) A correlation coefficient for modal vector analysis, Proceedings of the 1st International Modal Analysis Conference, pp. 110-116.

Aki K. (1957) Space and Time Spectra of Stationary Stochastic Waves, with Special Reference to Microtremors, *Bulletin of the Earthquake Research Institute*, Tokyo University, Japan, 25, 415-457.

Albarello, D. and Gargani, G. (2010) Providing NEHRP soil classification form the direct interpretation of effective Rayleigh-wave dispersion curves, *Bulletin of the Seismological Society of America*, 100(6), 3284-3294, doi: 10.1785/0120100052.

Borcherdt, R.D. (1994) Estimates of site-dependent response spectra for design (methodology and justification), *Earthquake Spectra*, 10, 617-653.

Diechmann, N. and Giardini, D. (2009) Earthquakes induced by the stimulation of an enhanced geothermal system below Basel (Switzerland), Seismological Research Letters, 80 (5), doi: 10.1785/gssrl.80.5.784

Iervolino, I., Giorgio, M, Chioccarelli, E. (2015) Markovian modelling of seismic damage accumulation *Earthquake Engineering and Structural Dynamics*, 45:441-461, doi: 10.1002/eqe.2668

Nakamura, Y. (1989) A method for dynamic characteristics estimation of subsurface using microtremors on the ground surface, QR Railway Technical Research Institute, 30 (1).

Parolai, S., Richwalski, S.M., Milkereit, C. and Fäh, D. (2006) S-wave velocity profiles for earthquake engineering purposes for the Cologne area (Germany), *Bulletin of Earthquake Engineering*, 4, 65-94, doi: 10.1007/s10518-005-5758-2.

Picozzi, M. and Albarello, D. (2007) Combining genetic and linearized algorithms for a two-step joint inversion of Rayleigh wave dispersion and H/V spectral ratio curves, *Geophysical Journal International*, 169(1), 189-200, DOI: 10.1111/j.1365-246X.2006.03282.

Tsionis, G., Papailia, A. and Fardis M.N. (2011) Analytical Fragility Functions for Reinforced Concrete Buildings and Buildings Aggregates of Euro-Mediterranean Regions – UPAT methodology, Internal Report, Syner-G Project 2009/2012.