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| | | Final Report |

**Project No:** 312718

**Project Acronym:** RECONASS

**Project Full Name:** Reconstruction and REcovery Planning: Rapid and Continuously Updated COnstruction Damage, and Related Needs ASSessment

# Final Report

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INSTITUTE OF COMMUNICATION AND COMPUTER SYSTEMS


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# PROJECT FINAL REPORT

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| **Grant Agreement number:** | 312718 |
| **Project acronym:** | RECONASS |
| **Project title:** | Reconstruction and REcovery Planning: Rapid and Continuously Updated COnstruction Damage, and Related Needs ASSessment |
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## 4.1 Final publishable summary report

### 4.1.1 Executive Summary

In a duration of 42 months (December 2013 - May 2017) and implemented by a consortium of 10 partners from 7 MS, RECONASS prototyped and delivered a holistic monitoring tool for buildings (critical or conventional ones) comprised of a multitude of technological components for assessing the status of the facility during normal operations and after extraordinary ones. RECONASS belongs to the realm of disaster management and the final outcome is a complete Information System for Crisis Response, Reconstruction and Recovery Planning (Disaster Management Platform, sensors, communications and software assessment modules) towards monitoring buildings. Its primary goal is to provide the stakeholders, be them civil protection agencies, building owners or insurance companies with an accurate, updated and near real-time assessment of the monitored facility's structural and non-structural status after an explosion, an earthquake or a fire. In more detail, RECONASS delivered a multidisciplinary Information System for Crisis Response, Reconstruction & Recovery Planning by researching, adapting and integrating cutting edge technologies: a) a compact and highly energy efficient local positioning system was prototyped which cooperates, under the deployment of a wide sensor network, with strategically placed strain, acceleration and temperature sensors; b) the aggregation of sensor information is realised by a robust, secure, intelligent and resilient communication module; c) a remote sensing framework complements the aforementioned data extraction methodologies, using air and space borne systems and; d) capitalising on the data derived from above systems, data fusion is enabled and overall structural and non-structural assessments are executed in the interoperable Post Crisis Needs Assessment Tool in regards to Construction Damage and related Needs (PCCDN). Such platform embeds the structural and economic loss and needs assessment modules which output appropriate data for comprehensively depicting (GUI featuring 2D/3D visualisations and a rich set of building information) the end-user with the structure's status, including external data (e.g. meteorological data, newsfeeds) whilst permitting information exchange among the response, reconstruction and recovery planning agencies.

RECONASS spanned across 3 periods of 14-month duration each. In the first period the overall system architecture, a mixture of technical and user requirements and subsequent specifications, emerged. Moreover, in the same period early developments of the RECONASS components were realised that have been finally prototyped during the second period. In the same period, early prototypes have been functionally stressed in a component test where miniaturised building components were monitored when subjected to blast loadings. Such process enabled refinement and prototyping of the final integrated system as well as design and planning of the demonstration activity (1:1 scale 3-storey building monitored by the RECONASS system severely stressed in two subsequent explosions, externally and internally), realised in third period. RECONASS widely disseminated its interim and final results, featuring more than 25 scientific publications, a vivid online presence though its website and social media, an end user group of more than 100 organisations, regular newsletter releases and 3 end-user workshops for incorporating user needs in the system design and final evaluation. Noteworthy, RECONASS successful results drive its exploitation goals for transforming the system prototype into a product within the Structural Health Monitoring domain. At present, patent filling for the tags, successful results of the pilot evaluation, a detailed cost-benefit analysis and switching to a product website (www.shoxsolutions.com), pave the way for the project's exploitation potentials, envisaged to be materialised by the creation of a joint venture, turning the consortium from a R & D focused entity into a commercial one.

### 4.1.2 Summary description of project context and objectives

RECONASS concept was driven towards providing a monitoring system to accurately assess the structural condition and related needs of single or grouped facilities (i.e. buildings). The RECONASS system that has been delivered encompasses novel technologies originating from different domains, seamlessly interworking with the aim to shorten the required time of assessments preserving precision and to establish an efficient updating process. The overall technology implemented in RECONASS is focusing on the case of reinforced concrete buildings that constitute the main type of construction of critical buildings in both earthquake prone countries of Europe, as well as, in rest of Europe and North America.

In more detail, the RECONASS work delivered a monitoring system for constructed facilities that provides a near real time, reliable, and continuously updated assessment of the structural condition of the monitored facilities after a disaster or attack, with enough detail to be useful for response, reconstruction, early and full recovery planning. The above assessment is seamlessly integrated with automated, near real-time and on-going estimation of the physical damage, loss of functionality, direct economic loss as well as needs of the monitored facilities and provides the required input for the prioritization of their repair. Another aim of this work has been, based on near real-time estimates of the structural damage of monitored facilities, the development of a methodology and the corresponding software implementation for the automatic, near real-time estimation of the resulting non-structural damage. Equally important, the functionality of the facility, total volume of debris from both structural and non-structural components in the monitored facilities, the cost and duration of structural and non-structural repairs as well as construction manpower and materials needs are evaluated. Moreover, RECONASS combines sensor-based damage assessment of the monitored facilities with remote sensing data to retrieve a holistic assessment on the damage. Additionally, the system provides seamless interoperability among heterogeneous networks to ensure that the required information from the monitored facility can reach the base-station in stringent time-constraints even under difficult conditions, such as post-crisis situations (e.g., post-earthquake). Finally, a post crisis needs assessment tool in regards to construction damage and related needs (PCCDN) has been delivered that primarily collects information from all monitored facilities in the affected region (e.g., the parliament, the Ministry of the Interior, hospitals, bridges). Subsequently, the PCCDN processes the information in order to provide recovery stakeholders with near real-time, reliable, continuously updated information, in the form that each one of the stakeholders' needs it. Example outputs include but are not limited to the following: structural and non-structural damage, shoring and demolition needs, loss of functionality, direct economic loss and the resulting needs in construction labor and materials for the monitored buildings. Component wise, the system is comprised of sensors attached and embedded in the building (accelerometers, strain and temperature sensors and localisation tags), of a complex communication infrastructure capable to capture sensor measurements in real-time and subsequently convey under any circumstances, securely such vales to the disaster management platform of RECONASS, the latter visualising the status of the building at all times as it embeds structural, non-structural and remote sensing algorithms (UAV and satellite data) which analyse and assess the condition of all elements comprising the monitored building.

For designing, developing, prototyping, testing, evaluating and ultimately delivering the abovementioned system, the 42-month work implementation has been divided in 10 work packages as follows: WP1 on User Requirements and System Architecture, WP2 on RECONASS Monitoring System – Accurate Positioning – Secure Communication, WP3 on Damage, Loss and Needs Assessment, WP4 on Synergistic Damage Assessment with Air and Spaceborne Remote Sensing, WP5 on Post Crisis Needs Assessment Tool in regards to Construction Damage and related Needs (PCCDN), WP6 on System Integration, WP7 on System Evaluation and the horizontal activities WP8 on Exploitation of Project Results and Management of Intellectual Property, WP9 on Dissemination Activities and WP10 on Consortium Management. In the following of present section a description of the entirety of project objectives at WP-level can be found including their accomplishment status.

**WP1 Objectives and Accomplishment status:**

- To analyze SotA structural damage, loss and needs assessment tools working out current shortfalls and misfits to be addressed in RECONASS (Accomplished and delivered in D1.1 featuring relevant SotA)
- To focus on the needs of recovery stakeholders at applications and operational level (Accomplished and delivered in D1.2 featuring the proceedings of the first RECONASS end user workshop, in Berlin, Germany on 24th -25th of March 2014, where 14 End-Users participated and has been hosted by THW)
- To define (i) functional (ii) operational and (iii) performance requirements for the proposed integrated package based on the end-users needs (Accomplished and delivered in D1.3 featuring user requirements)
- To investigate the regulatory framework, legal aspects, standards of the monitoring system, the software and the communications (Accomplished and delivered in D1.4 featuring the system design as a whole)
- To set the system design and provide the final system specifications enabling the system to operate in an interoperable manner (Accomplished and delivered in D1.4 featuring the system design as a whole)

**WP2 Objectives and Accomplishment status:**
- To design of a local positioning system (LPS) (Accomplished and delivered in D2.1, D2.2, D2.3 and D6.1 featuring the LPS prototype)
- To provide the sensor nodes (Accomplished and delivered in D2.1, D2.2 and D2.3 featuring the strain, temperature, acceleration sensor prototypes and relevant communication nodes)
- To provide prototypes for system verification (Accomplished and delivered in D2.1, D2.2, D2.3 and D6.1 featuring the strain, temperature, acceleration, positioning sensors and communication module prototypes)
- To define the appropriate network interfaces (Accomplished and delivered in D2.1, D2.2 and D2.3 featuring the communication module prototype)
- To design a resilient, robust, secure and interoperable communication network for the specific application (Accomplished and delivered in D2.1, D2.2 and D2.3 featuring the communication module prototype)

**WP3 Objectives and Accomplishment status:**
- Non-linear analyses of component testing, and support of setup design of pilot test. (Accomplished and delivered in D3.1 featuring Finite Element analyses for the structural response of both single slabs and multi-node concrete frame supporting the setup and planning of the pilot test)
- Develop the algorithms that correlate tag data with the structure that has emerged from the disaster. (Accomplished and delivered in D3.1 featuring specialised software using displacement vector for each tag)
- Develop the Structural Assessment Module. (Accomplished and delivered in D3.2 featuring algorithms of the monitored building under operating, seismic, blast and fire loading)
- Develop the Economic Loss and Needs Assessment Module (Accomplished and delivered in D3.3 featuring a unified methodology to estimate loss and needs from all extreme events under consideration)

**WP4 Objectives and Accomplishment status:**
- To develop methods for generation and local calibration of regional damage information based on satellite information with site-specific sensor information generated in WPs 2-3 (Accomplished and delivered in D4.2 and D4.3 by developing a method for automatic 3D modelling of the buildings using image based mapping through machine learning)
- To develop a methodology for automatic multi-view (5 directions) per-building exterior damage assessment of buildings equipped with sensors networks developed in WPs 2-3, using airborne oblique imagery (Accomplished and delivered in D4.1 by developing a methods for automatic identification of damage evidences such as debris, spalling and structural gaps due to damage, using the image textures and geometric features from the image-derived 3D point cloud)
- Extension to neighboring buildings, and additional damage parameters such as extent and amount of rubble/debris, as well as site accessibility (Accomplished and delivered in D4.3 featuring a method for the automatic identification of buildings in a large scene where the neighbouring buildings can be automatically detected given the images from the drone and the 3D point cloud derived from them)

- To investigate how additional sensor types (e.g. chemical) affixed at the exterior of the monitored buildings can be coupled with remote sensing data to determine the extent and possible consequences of non-structural damage (Accomplished and delivered in D4.3 featuring a conceptualisation of a sensor network extension)
- To provide prototypes for system verification (Accomplished and delivered in D4.3 featuring procedures developed to integrate UAV-derived damage indicators and information coming from the internal sensor network, using a common CAD system)

**WP5 Objectives and Accomplishment status:**
- Provide an open interoperable platform enabling the fusion and integration of external data and information (Accomplished and delivered in D5.1 featuring development of on open service oriented architecture platform)
- Allow for the customization and future expansion of the system in order to include additional building structures, additional type of structures, additional loadings, additional sensors and additional software in order to process additional information in order to cover the assessment of all needs (Accomplished and delivered in D5.1. D5.2, D5.3 and D5.4 featuring development and adaption of OGC standards for sensors' data and an open source enterprise service bus solution supporting the attachment of various data sources)
- To provide the recovery stakeholders, inter alia, with near real-time and continuously updated 3D representations of the building in detail (Accomplished and delivered in D5.4 and D5.5featuring embedment of Google Maps, BIMServer and point cloud to present the user the results of calculation modules)
- In regards to the whole affected area, to provide the recovery stakeholders with a calibrated and validated map in record time (Accomplished and delivered in D5.4 featuring BIM Model and point cloud correlation)
- Based on external data to provide stakeholders with additional information on, for example, open roads to go to a specific location or availability of electricity. (Accomplished and delivered in D5.4 and D5.5 featuring GDACS alerts, weather and traffic alerts feeding into the PCCDN prototype)
- Allow for active collaborative work between the civil agencies/authorities and the recovery teams. (Accomplished and delivered in D5.4 and D5.5 featuring open interfaces of the PCCDN tool made available to authorised users)

**WP6 Objectives and Accomplishment status:**
- To provide the integrated package in a format compatible for installation in the laboratory test in WP7. (Accomplished and delivered in D6.1 via two integration meetings, packaging and installation planning and execution prior to the pilot test and documentation of the integrated system)
- To provide platform and systems which integrate monitoring information into network systems and protocols, for being stored and used in a user friendly, transparent and reliable way, with maximum efficiency. (Accomplished and delivered in D6.1 featuring documentation of the integrated system)

**WP7 Objectives and Accomplishment status:**
- To experimentally evaluate the local positioning tags in WP2 and the theory for the assessment of the structural condition of the structure that has emerged from the disaster developed in WP3 (Accomplished and delivered in D7.1, D7.2 and D7.3 featuring successful results and evaluation of component and pilot testing activities)
- To evaluate the non-structural damage assessment developed in WP3 (Accomplished and delivered in D7.2 and D7.3 featuring successful results and evaluation of component and pilot testing activities)
- To evaluate the whole RECONASS system both at the laboratory test and in pilot scenarios simulating seismic events and terrorist attack. (Accomplished and delivered in D7.1, D7.2 and D7.3 featuring successful results and evaluation of component and pilot testing activities. On 25th and 30th of August 2016 in Älvdalen, Sweden a large demonstration was successfully set up by the RECONASS Consortium. The demonstrator concept involved the instrumentation of a 3 storey building of reinforced concrete, with the RECONASS sensors and prototypes and the execution of massive blasts from its exterior (400 Kg of TNT) and its interior

(16 KG of TNT) to evaluate the RECONASS system in a live experiment, as close as possible to realistic conditions. The RECONASS demonstrator showcased how the RECONASS system as a whole assesses rapidly the structural condition of the monitored building after a disastrous event.

**WP8 Objectives and Accomplishment status:**

- To file for patents for the proposed local positioning tags and communication system (Accomplished and delivered in D8.3 featuring patent filling for the local positioning tags system)
- To create awareness of the project results within the Civil Protection administrations and the Security organizations in the EU and abroad (Accomplished and delivered in D8.3 featuring more than 100 organisations in the end user group, presence at CEN-CENELEC JWG8 for standardisation efforts, clustering activities with more than 8 EU funded projects and collaboration links with Applied Science International, Norwegian Defense Estates Agency, SATWAYS and JRC; for the former three in regards to their participation to the instrumentation process of the pilot (at their own costs) and for the latter towards interfacing the disaster management platform developed in the project (PCCDN) with JRC tools (Field Reporting Tool) developed, hence improving the user experience with additional functionalities.)
- To develop the strategic approach, define the appropriate business plan and elaborate a suitable market model for commercialization of the project results (Accomplished and delivered in D8.1 and D8.3 featuring a wide exploitation strategy that includes, inter alia, competitor analysis, end user analysis, cost benefits analysis, sales forecast, product video and website , brand 'SHOX – Structural Health Monitoring in a box')
- To prepare support products, including documentation, in a form that can be understandable and accepted by potential users, help in technology transfer and provide necessary advice and support (Accomplished and delivered in D8.2 and D8.4 featuring a brochure and details for a web demo of the RECONASS PCCDN tool)

**WP9 Objectives and Accomplishment status:**

- To widely disseminate the existence of the project and its results and achievements (Accomplished and delivered in 9.2 and D9.4 featuring a multitude of dissemination activities such as more than 25 scientific publications, a vivid online presence though its website and social media, an end user group of more than 100 organisations, regular newsletter releases and 3 end-user workshops for incorporating user needs in the system design and final evaluation)
- To train the staff from THW and associate users (Accomplished and delivered in 9.3 during the 2nd end user workshop and during the pilot demonstration activity)

**WP10 Objectives and Accomplishment status:**

- To ensure the project's proper management and the achievement of its objectives in accordance with its time schedule and budget large; to receive and distribute financial contribution; to provide administrative management; to efficiently communicate between the participants and report regularly to the participants and to the Commission; to provide continuous monitoring of the project progress and assure its quality; to guarantee that all contractual, legal, ethical, security, society and gender equality issues related to the project research are properly considered and any relevant conventions are respected and; to define the project security plan and procedures (Accomplished and delivered in D10.1, D10.3, D10.4, D10.5, D10.6, D10.7 and D10.8 as projected in the Description of Work)

### 4.1.3 Description of main S & T results/foregrounds

The present section describes all project S & T results/foregrounds for the entire project duration, the latter being of 42 months starting on December 2013 until end of May 2017. The project lifecycle comprised of 10 distinct work packages has been divided in three periods each of them comprising of 14 months. All S & T results/foregrounds have been delivered in the context of the first seven technical work packages of the project, as the latter three are dealing with horizontal activities, namely dissemination, exploitation and project management.

First period (M1-M14) took place from December 2013 until January 2015 during which the work of WP1 was concluded while the main technical WPs i.e. WP2, WP3, WP4, WP5 and WP7 have commenced. The latter ones capitalise mainly on the end user requirements extracted - through questionnaires and a workshop - from a plethora of end users originating from different categories. Of equal importance input are considered the technical requirements, the RECONASS subsystems'/components' specifications as well as the overall RECONASS architecture that set the basis for further developments and research activities. At the same time all WPs previously mentioned fuel with their outputs the running tasks of WP7 towards the very first RECONASS component testing that will in turn provide the initial set of tangible field results applied on simple and complex structural components similar to the ones of the final building to be constructed later in the project's course.

Second period (M15-M28) has been realised from February 2015 until March 2016, during which the entirety of technical WPs, namely WP2 on Sensors and Communications, WP3 on Damage Assessment, WP4 on Remote Sensing and WP5 on the RECONASS disaster management platform for Critical buildings (i.e. the PCCDN tool) have been running in parallel showcasing significant progress towards functional prototypes. Noteworthy, the 2nd period includes the beginning of the integration activities (under WP6) towards the interfacing and interworking of the RECONASS integrated system. Moreover, during the same period the individual RECONASS components have been preliminary evaluated under blast conditions over the execution of the component testing. The testing activity also gave the opportunity to assess and predict the building reaction to the final pilot in which a 3 storey building instrumented as RECONASS proposes will be subjected to 2 subsequent blasts (an external and an internal one). The latter activities have been realised under WP7 which encompasses the pilot execution and the system evaluation. On the latter an internal plan has been set that includes Key Performance Indicators for the whole system, Use cases as well as the description of the mock up exercises to validate the RECONASS system's usability.

The third and final period of RECONASS (M29-M42) has been implemented during April 2016 until May 2017. In this period intensive integration efforts have been realised under WP6, through two dedicated integration workshops for resulting the RECONASS integrated system. In this period the all RECONASS monitoring system prototypes have been delivered; the entirety of sensors integrated within the communication system through WP2, the structural and non-structural assessment modules through WP3, the remote sensing assessment implementation through WP4 and the disaster management platform of RECONASS (namely the PCCDN tool). All disparate components have been integrated into a fully functional integrated system to realise the large pilot demonstration of the project. The RECONASS demonstration has been a large and complex task implemented in various stages as it required the construction of the test building in a remote location in Sweden, the full instrumentation of it and the execution of two explosions, an external and an internal one, to stress and showcase the functionalities of the system for assessing the test building's condition after such an extraordinary event. The first stage, in April 2016, when the test building's erection commenced has been the installation of the strain sensor and the associated communication units in its foundations. Prior to this an integration workshop has bene realised to test all RECONASS systems end-to-end. In June 2016, a 2nd integration workshop has been realised to correct shortcomings identified since the first one so that smooth information exchange is realised from all sensors to the PCCDN tool and ultimately all assessments are properly executed. During August 2016 the second stage of the pilot has been realised where all partners contributed to the instrumentation of the now erected building. The final tests have been scheduled for end of August 2017 where the RECONASS demonstration successfully concluded attracting a wide range of stakeholders that witnessed the full scale demo. During and after the test the whole RECONASS system has been put under evaluation in order to assess functionalities and result in the final validation of the system. Such evaluation process has been concluded in the context of the final international RECONAS workshop that has been organised in conjunction to the ISCRAM 2017 conference in Albi, France.

The most important S & T results/foregrounds of the above mentioned WPs' progress will be briefly but concisely described below for the entire RECONASS lifecycle:

RECONASS technical work commenced with **WP1** which has initially focused on the State-of-the-Art analysis of Assessment Tools and on the extraction of the preliminary user requirements, in line with task T1.1, reported within D1.1. In parallel, special emphasis has been given on the formation of the RECONASS user group, as expected from T1.2, that comprises at the end of the project of more than 100 major end-users that belong in the following categories: A) Governmental Emergency / Disaster Response Organisations, B) Non-Governmental Emergency / Disaster Response Organisations, C) Public Operators of Critical Buildings, D) Private Operators of Critical Buildings, E) Organisations involved in the development of remote sensing based damage maps, F) Organisations involved in synoptic damage prediction based on acceleration measurements, insurance companies, etc.. The first RECONASS End Users Workshop has been realised in Berlin (D1.2) as an additional mean to retrieve user requirements through actual interaction with end users apart from the completion of questionnaires whilst at the same time to introduce the RECONASS concept. Based on the above outcomes T1.3 concluded with the delivery of D1.3, i.e. Final user requirements. Last but not least, the full specification set for the RECONASS system has been realised, reported in D1.4, encompassing through intense collaborative work among partners, the standards and best practices for all RECONASS domains (T1.4), the transformation of user requirements into technical requirements to be subsequently translated into specifications of the monitoring system and the assessment modules of RECONASS (T1.5, T1.6) to conclude with providing the RECONASS system architecture including all of its components and their interactions (T1.7). Within Task 1.7 on RECONASS system architecture started also on, **the detailed overall architecture divided in two distinct subsystems – the monitoring and the assessment one - has been designed and described including the interactions, interdependencies and data flows between all the RECONASS modules and their respective interfaces**. The RECONASS partners have derived technical specifications applied to the following components that reflect the overall RECONASS system: network of sensors (acceleration, temperature and strain and local positioning tags); data-hubs (for collecting the sensors and tag data); communication gateway module (to gather all the data in the appropriate format); PCCDN tool (consisting of the structural, economic loss and needs assessment modules); UAV system.

The work delivered in **WP2**, commenced in first period, includes the design, development and prototyping of the full monitoring system comprising of the local positioning system, the accelerometers, the strain sensors and the temperature sensors interconnected over a multilayer communication module that is built of wireless/local sensor networks, local area networks and a wide area network. The WP2 work for the first period is reported in D2.1 on LPS and sensor node system architecture defining the architecture and the interfaces of the particular system components, based on the requirements defined in D1.4, on a close-to-hardware level. Within the first reporting period, the establishment of the local positioning system and the proposed tags-coordinator LPS topology and structure has been realised; physical details of the strain, acceleration and temperature sensors and their performance parameters have been produced and the communication module and its components of gateway, data hubs and the sensorial interfaces have been specified including both hardware to be installed as well as communication technologies and protocols to be utilised. The WP2 work for the second period is reported in D2.2 on LPS and sensor node defining the prototypes, the topology and the circuit design of the particular system components. Prototyping of the local positioning system and the proposed tags-coordinator LPS topology and structure has been realised; as well as of the strain, acceleration and temperature sensors. In more detail, WP2 on RECONASS Monitoring System- Accurate Positioning – Secure Communication is implemented by the sensor and communication providers.. Within the 2nd reporting period, D2.2 has been delivered which serves as an accompanied report of the LPS, strain sensors, temperature sensors and accelerometers' prototypes. Towards such progress extensive laboratory testing, firmware development, short-scale manufacturing has been realised. At the same time the sensors prototypes have been successfully tested against blast impact, mainly for their durability attributes, in the component testing held in Sweden. The tests of the Local Positioning System (LPS) prototypes (8 nodes have been manufactured) in the laboratory environment gave excellent results both in precision and accuracy readings, advancing the current state-of-the-art. All other sensors, namely the accelerometers, the temperature and the strain sensors have been tested and benchmarked fully achieving the requirements posed by the structural engineers (see D1.4). In regards to the communication module, the hardware to permit the full range of availability, reliability, robustness and performance requirements has been specified. Additionally, up to the conclusion of the 2nd period the communication module has been nearly prototyped, including its full set of functionalities for in- and out- building communications in a robust, reliable and resilient manner. Moreover, physical and remote connectivity has been established between all network entities of the RECONASS communication module in a miniaturised version of the overall RECONASS system. During the 3rd reporting period the activities held in WP2 included mainly the full scale prototyping of the RECONASS communication module which has been developed within the RECONASS Project for delivering all types of communication from the sensors up to the disaster management tool (PCCDN tool), the latter being the graphical user interface (GUI) that a user operates for monitoring a given constructed facility (be it a critical or a conventional one). The prototype covers a) communication between the sensors and the wireless sensor nodes, b) communication between the wireless sensor nodes and the data hubs (data aggregation points), c) communication between the wired sensors and the data hubs, d) communication between the data hubs and the communication gateway, the latter being the central communication node of the overall monitoring system and e) communication between the communication gateway and the PCCDN tool, the latter enabling depiction of the sensor related information and relevant structural and non-structural assessments into a graphical user interface that uses a building information model (i.e. building design). The RECONASS communication module has passed two phases of integration (within the respective workshops of WP6) and fine-tuning has been performed towards its installation within the test building of the RECONASS demonstration activity.

**Concerning the Local Positioning system and the sensors**, the most important activities include the conclusion of prototyping, the component testing activities and the remote integration tasks. Transversal to these activities the logic that governs the communication module of RECONASS has been developed encompassing all network layers and devices. To fulfil the cost, size and power consumption requirements of the RECONASS project, **the LPS prototype** was targeted to integrate most of the analogue building blocks into integrated circuits. The core of the LPS module is the system chip. The chip implements a dual band radio frequency front end for frequency modulated continuous wave (FMCW) radar systems in the 2.4 and 5.8 GHz ISM bands. The receive path consists of a low noise amplifier (LNA), frequency mixer, an off-chip base band filter and a variable gain amplifier (VGA). The most important part of the ASIC is the integrated phase locked loop (PLL) with a highly linear chirp generator for FMCW applications. It is completed by a wide band voltage controlled oscillator (VCO), operating from 4.6 to 6.5 GHz, which allows it to be used for both targeted ISM bands by employing a switchable frequency divide-by-two. The transmit path of the chip contains a driver with -3dBm output power, which can either directly drive an antenna for low range applications or an external RF power amplifier. The chip also includes a temperature sensor, which can be used to calibrate different temperature-dependent distance offsets in ranging and positioning applications. To achieve larger ranges with the system and to penetrate obstacles with the radar signals while keeping a good signal-to-noise ratio, an external power amplifier is connected to the system chip. It is also a custom design, which is able to handle both targeted ISM bands, thereby saving external components and reducing system cost. The RECONASS LPS prototype module consists of a stack-up of 2 printed circuit boards (PCBs) and a 12V battery supplying the unit, as it can be seen below. The top board is the digital PCB. It is used for control and power supply of the whole unit. Furthermore, it contains a user interface for testing and fundamental settings (switches and LEDs), as well as debugging connectors (pin headers and a micro

USB interface). It also includes the analogue and radio frequency (RF) PCB. It contains the components necessary for radio frequency distance measurements and LPS protocol handling. Those components include both designed ASICs as well as standard components like filters, amplifiers and analogue-to-digital converter. The lower board is the interface PCB. It provides components for interaction with the rest of the RECONASS monitoring system. This can be e.g. a ZigBee or Ethernet interface. All PCBs have a size of 100 mm x 70 mm. The applied modularization paradigm allows separate testability of the components, exchangeability in case of damages or redesigns as well as cost optimization, by using only the necessary PCB manufacturing technologies (i.e. impedance-controlled, expensive PCB layer stack only for the RF board, cheap multi-layer setup for the digital boards). During the prototyping process, laboratory tests have been performed by TUD which manufactured a set of 6 up to 8 nodes for positioning, namely an indoor corridor scenario and an outdoor garden scenario. The preliminary results obtained for the positioning tags developed for RECONASS application showed significant advances in the SotA in both accuracy and precision measurements. Noteworthy, the development of a LPS with precision of less than 9cm in an indoor scenario not only exceeds current state-of-the-art systems, it is also vital for accurately measuring displacement of the tags during the pilot. Furthermore, the development of a 3D cooperative positioning algorithm is an important step to use the system for structural health monitoring. Moreover, the LPS prototype including the casing specified for the protection of the electronics has been subjected to blast impact during the component tests. The main attribute to be tested was durability of electronics. The test outcome was successful as the case protected the electronics and maintained their functionality after the blast.

**On the strain-gauges**, the sensor choice made is based on structural engineers specification of measuring range (-25000με to +25000με). Selection was based on the: maximum strain to be measured, material to which it is bonded and environmental conditions. All gauges tested are of 120 ohms resistance, and were obtained from HBM. The estimated power to be dissipated for 5 and 10V excitation are around 52 and 208mW respectively in each arm of Wheatstone bridge. Power dissipation increases with excitation voltage and also leads to higher signal-to-noise ratios. So considering the technical design specification in D1.4, an excitation voltage of 10V was selected. Note that 10V excitation is commonly used with a bidirectional data connection to data-hub for off-the-shelf strain devices. Hence, it was considered ideal for the RECONASS project. The strain gauges selected were "1-LY41-20/120" & "K-LY4-1-11-120-3-1", the latter type comes with lead wires that were pre-soldered. The strain sensor prototype developed is combined with Bridge Completion Module (BCM). Essentially, it is a Wheatstone bridge that provides the voltage output corresponding to a resistance change at the gauge. It is balanced when the resistance of the components in the arms yields zero bridge output For the strain prototype, rigorous testing was performed in which steel-rebars of 8-20 mm diameter were subjected to tensile loads at ARU laboratories. Strain-gauges were installed and variation in analog voltage output is measured with a micro-Voltmeter. Strain was recorded independently with two strain meters P3 from Vishay and DP-25 from OMEGA. The same strain sensors were subjected to blast loading during the component testing and the results showed that the measurements obtained fully cover the needs of structural engineers.

**On the temperature sensor**, the product "CSmi-SF15-C6/3 Miniature Pyrometer" was used for laboratory testing. This Pyrometer meets the specified temperature range of -40 and 1030°C set in D1.4 and D2.1. The spectral response of this product is 8-14μm and produces an analogue voltage proportional to the detected temperature. This Pyrometer provides analogue output in ranges 0-5V or 0-10V depending on user request. This unit is equipped with a metric M 12×1 thread and can be installed either directly via the sensor thread or with the help of a hex nut to the mounting bracket. The unit comes with a USB programming adaptor. Using Compact Connect software, it is possible to change analogue voltage output setting, minimum and maximum temperature range. The default pre-setting temperature and analogue voltage signal range of this unit are 0-350°C and 0-3.5V respectively. These Pyrometers seamlessly integrate with data-acquisition systems. Thus real-time and continuously updated assessment of temperature changes can be monitored for facilities. Simple tests gave useful guidance on calibrating these sensors for the future deployment in pilot and large-scale testing.

**The accelerometers** used in RECONASS are the state of the art in structural monitoring devices, and are developed by GeoSIG. These are widely used across the world for monitoring of structural buildings, bridges and other critical structures. Type AC-43 accelerometers have been tested towards requirements of RECONASS project. These are based on multiple MEMS sensor cells that measure in parallel. This technique was developed to minimise the noise and to improve the performance of the accelerometer. Furthermore, these accelerometers are available at a reasonable cost. It is anticipated to install 4 accelerometers per building floor thus a total of 16 to be installed in the test building. All accelerometers will be installed in the same orientation. Positive X will be aligned to north and positive Y will be aligned to east. The sensors will be mounted flat on the floor of level 0, level 1, and level 2 and on the roof of the building. The accelerometers have been subjected to blast load during the component testing, mainly to test their durability. Based on the component testing's results installation and levelling decisions were made to satisfy the requirements posed by the structural engineers from the points of the building they wish to receive accelerations for the pilot test. The accelerometer enclosure is designed for easy installation, levelling and maintenance. This allows installation with minimal training and makes levelling of the sensor simple and flexible. To install the accelerometer, a hole is drilled on the installation surface, with a diameter that fit the anchor. The three screws on the edges of the enclosure are used to tighten the enclosure to the wall. The fixing and levelling screw pulls the enclosure towards and away from the wall respectively. A bubble level is placed on the top of the sensor housing to correctly set the level by adjusting with the three levelling screws. This installation methodology is convenient as it allows easy orientation of the sensor even on uneven surfaces.

**Regarding the data hubs**, great effort has been done to make ZigBee implementation into the data hubs as seamless as possible, ensuring that this new data acquisition channel is implemented in a way that the user will see minimal difference between a wired sensor and a wireless ZigBee sensor, from the configuration point of view. This provides easy adoption of the solution, less requirements for special training and minimizes the amount of work required to adapt the data hubs to the RECONASS system. In close collaboration with ICCS and TUD, the communication flow between gateway and data hub as well as between sensors and data hub has been developed.

**The prototyping of the communication module and the RECONASS Gateway** include a wide range of functionalities as follows. On a bottom-up approach, the communication module is responsible to enable data reception from the in-building sensors (in RECONASS case, these are strain, temperature, acceleration sensors and local positioning tags but the software and hardware enablers remain functional for any type of sensors). In more detail, all such data are aggregated in 1st tier communication nodes, namely the data hubs which are responsible to capture raw synchronised data and encapsulate them into XML-based files. Temperature and acceleration sensors are transmitting values via analogue cables whereas strain and positioning sensors are wirelessly transmitting data over standardised 802.15.4 interface (ZigBee Pro). The data aggregation and file conversion logic is governed by specialised software which is embedded in the 2nd tier node, namely the RECONASS communication gateway which manages the entirety of transactions between the communicating elements (intra and inter-system). The process described refers to the data management layer of the gateway and further to data collection it includes data validation and local storage. Moreover, the gateway implements sensor management functions, enabling a set of semiautomatic tasks in regards to 1st tier devices, be it sensors or network nodes. Such functions include sensor status updates (whether a sensor configured properly), abnormal behavior alerting (when a sensor is failing), user authentication and authorisation (for all sensors joining the network or users access-ing network devices), data encryption (for all data exchanged within the established network) and device configuration (change of device set up en operations). The connectivity between 1st and 2nd tier devices (data hubs and gateway) is facilitated by the use of the NetQuake Server, either wirelessly (802.11) or wired (802.3) implementing failover capability. Moreover, the sensor management layer is responsible for transforming 1st tier data to OGC-SWE compliant ones to facilitate sensor observation, tasking and alerting services required by the 3rd tier communication as services to remote databases. 3rd tier communication refers to the ability of the gateway to access external platforms or services, thus exchanging data over wide area network (WAN) interfaces; basically, bi-directionally exchanging in-building sensor and device data with remote data-bases for further processing and/or visualisation. To do so, the gateway implements the security & tunnelling and the smart routing layers. The former is responsible to securely establish a virtual private network (VPN with use of private keys and certificates) between the hosts (gateway's WAN interfaces) and the remote database as well as to monitor in-building (local) networks' performance and take re-routing actions if necessary. The latter includes customised and adaptive routing protocols (open variants of OLSR and AODV) towards the best utilisation of several IP interfaces (such as mobile networks, satellite and 802.11). Such optimum usage of network resources is also applied by the implementation of the specialised algorithms (adaptation of Weka Algorithm) that combines performance metrics such as link quality, error rate and link sensitivity with data throughput needs. The algorithm exploits the nearest neighbors' principle to route the traffic over the available IP interfaces. The Communication Module and Gateway Implementation developed in the RECONASS project, and reported in D2.3, governs the entirety of communications among sensor and network nodes within the monitored building or to and from remote databases. This solution has been created to support secure, interoperable and resilient data exchange either in crisis conditions or in normal operations. The data management logic implemented allows for future extensions of the system, as it is capable of hosting any type of sensing device and supporting all-IP data exchange, permitting for the customised hardware and the in-house software to adapt numerous monitoring applications across several domains. The RECONASS Communication module and the gateway implementation have been integrated to the entire RECONASS monitoring system (sensors and PCCDN tool) during the 2nd integration meeting that took place in Dresden in June 2016. Following the final fine-tuning of the prototype the solution has been successfully installed and tested within the RECONASS Pilot demonstration that realised in Älvdalen, Sweden in August 2016.

**WP3** commenced on M8 of the project receiving as an initial input the outcomes of WP1's work in regards to the specifications of the RECONASS modules and the overall system architecture as well. This facilitated the kick-off and early progress of T3.1, T3.2 and T3.3 towards the definition of the development solutions that deal with the Algorithms that correlate tags' position with the structure that has emerged from the disaster, the structural assessment module and the loss and need assessment module to provide holistically analysis of damage state of structural and non-structural elements, loss and related needs. In particular the definition of the data model, the detailed analysis of the relationships between WP3 and WP4 has been carried out, mainly in terms of building modelling and definition of the data model and input/output data flows. During the 2nd reporting period, WP3 on Damage, Loss and Needs Assessment was completed, as planned, with Deliveries D3.1, D3.2 and D3.3. The work includes: (a) tangible results in regards to non-linear analyses of component testing and development of algorithms correlating tag position with the structure that has emerged from the disaster. In that sense, T3.1 concluded as planned, with the delivery of D3.1. In D3.1 the results from the FE analyses showed good agreement with the component testing measurement data – under T7.3.1 – for the structural response of both single slabs and the multi-node concrete frame. (b) structural assessment under operating, seismic, blast and fire loading, exclusively based on measurements from the RECONASS sensors that is being reported in D3.2 and (c) assessment of the loss and needs of buildings damaged under any of the extreme events under consideration. This assessment, which is reported in D3.3, is based on the structural response of the building and includes all structural and non-structural elements. Moreover, it is based on a detailed taxonomy of all of the above components, that, in order to facilitate global use of the models is consistent, as much as possible, with existing taxonomies developed for national or global use.

**On the development of Finite element (FE) models** for both the single concrete slabs and the multi-node concrete structures tested and reported in D7.1, relevant descriptions follow. Air-blast simulations and structural response simulations were performed independent of each other, with the air-blast pressures from simulations applied as load functions on the structural FE model, i.e. the analyses models were uncoupled. This is considered as a suitable analysis setup for concrete structures subjected to short duration air-blast from a high explosive charge. The use of coupled analyses, i.e. incorporating the fluid structure interaction (FSI) in the analyses, with updating of the structure's deformations during the air blast simulation is much more complicated. This later approach was not considered to give significant increase of the accuracy of the results for this type of concrete structures, and would require a considerable increase in work and also computational resources. The air blast and structural analyses were performed to determine a suitable charge size for the two different types of concrete component tests. Furthermore, for each of the two component test structures, i.e. single two span slab and multi-node structure, several analyses were performed to determine their responses for various blast loads. The aim of the analyses was to determine the suitable charge size and distance for the half scale component tests, and to verify the FE methodology based on the test results. Overall these simplified FE analyses show a good agreement with the tests. In general, it is difficult to capture the limit for a catastrophic failure, and a more systematic approach with an increased number of tests are needed to verify that a structures ultimate bearing capacity is correctly determined based on FE analyses. However, there are parts of the methodology for the FE analyses that can be improved for future analyses. The FE analyses were performed without a fluid structure interaction in the models. This is a suitable solution to reduce the complexity of the problem when massive concrete structures are analysed. However, in the case of lightweight structures it may be necessary to include a fluid structure interaction (FSI) in the model. The FE analyses and component tests in this work only consider loading cases with external detonations, for an internal detonation there are several other factors that need to be addressed. One major concern is to what extent the afterburning of the gases from a high explosive detonation increases the pressure inside a room or building. Modelling of this requires advanced burn models for the high explosive, and also that the actual configuration of the house is considered to obtain reliable results. Moreover, to help determine the possible damages of a monitored structure after a disastrous event, a comparison of positional data from the tags located in the structure at different times has to be done. The 1:2 scale tests and FE analyses of concrete slabs showed minor damage for approximately 2 mm permanent deflection, and for an increased blast resulting in approximately 8 mm permanent deflection the slab showed several cracks along its length. **The positional data from the position tags** are gathered by the PCCDN tool and then sent to a SOAP (Simple Object Access Protocol) web service from FOI that calculates the displacement vectors for all tags. The current positions of the tags will be compared to both their original and last known positions. The structure of the web service request has been developed. Every request to the web service includes the original, previous and current positions of all tags.

**On the structural assessment module**, based on monitoring data from strain, acceleration, displacement and temperature sensors installed in reinforced concrete building structures, in combination with the use of a commercially available non-linear structural analysis software is developed, resulting to the near real time estimation of the structural condition for the structural members as well as the stability of the whole structure due to the following events: 1) Normal operating conditions, 2) Earthquake, 3) Explosion and 4) Fire.

The module consists of the following parts. Part 1: Long term estimation of the variation with time of the actual loads applied on the structure and the resulting structural response. The module will receive in specific time intervals the inputs from the strain sensors installed on three reinforcing bars at corners of the bottom cross sections of the columns in the ground floor and will calculate the axial forces and bending moments developed. Furthermore it will calculate possible differential settlements and the percentage of the design live loads applied at the time of the measurement. By using a commercially available non-linear structural analysis program it will estimate the safety factors at critical cross sections of the structural members corresponding to the calculated loads and differential settlements.

Part 2: Short term estimation of the structural integrity due to the oscillations stimulated from earthquake. As a first step, the sequences of horizontal displacements at two extreme points of the floors and the foundation will be calculated after double integration of the inputs from the accelerometers. As a second step, these displacements will be introduced as imposed displacements to the commercially available non-linear analysis program on the structural model of the building. From the results of the analysis will be estimated (a) the local damage index at the critical cross sections of the structural members based on an energy based damage criterion, and (b) the overall instability index of the whole structure. Part 3: Short term estimation of the structural integrity due to the oscillations stimulated from the blast after explosion. The reduced resistance of members heavily damaged from the blast is introduced in the structural model and the analysis is executed as in the part 2. Part 4: Thermal effects on the strength of the structural members. A fire usually follows a blast implying the development of high temperatures varying with the position in the building and with time. The module will receive the inputs from the temperature sensors distributed over the whole structure. The temperatures at the position of the critical cross sections of the structural members and their variation with time will result from a space interpolation module. The rate of the heat quantity transferred to the structural members from the fire following the blast will be estimated and so will the reduced strength of concrete, steel and the critical cross sections. For this purpose the values of thermal conductivity, specific heat and thickness of concrete covering the reinforcing steel bars will be added to the properties of structural materials. The module calculating the internal forces will be modified by the introduction of the respective laws of variation of strength and deformability properties for the different finite elements constituting the mesh over the area of each cross section with respect to their depth from the free surface of the member. Part 1 is needed to provide input to the other Parts (on earthquake, explosion, and fire) on the structural condition at the time of the disaster. Part 1 depends on strain sensors embedded during the erection. In existing buildings where the installation of strain sensors is not possible, Part 1 can be eliminated and the structural assessment for the normal operating loads can result from the analysis of the structure for the known values of the dead and the quasi-permanent loads and the estimated value of the actual live load during the normal operation. This will still permit the evaluation of earthquake or fire structural response in existing buildings (accelerometers and temperature sensors do not need to be embedded and can be easily installed in existing buildings). This assessment can be used to direct structural engineers to locations of physical damage, even if they are concealed behind architectural finishes. Moreover, this assessment has been used with construction cost-estimation principles to estimate repair cost which is invaluable for quickly arranging for financing. The parts 1 and 2 consist of the software prepared for the MEMSCON project (www.memscon.com) properly refined to accommodate data and procedures destined to the incorporation of the parts 2 and 3 in the single module. The following innovations are introduced in the treatment of the structural assessment procedure. The analytic formulas for the constitutive law of the concrete are extended to contain expressions for the unloading and reloading branches which are developed during the cyclic repeated loading. Similar extension of the analytic formulas for the constitutive law of the reinforcing steel is introduced for the case of the cyclic repeated loading. A reconstruction procedure of the hysteresis loops pattern at the plastic hinges developed during a cyclic repeated loading due to earthquake or explosion. A calculation procedure for the estimation of the damage index at the plastic hinges is introduced based on the dissipated energy which is estimated from the corresponding hysteresis loops pattern. This constitutes the justification of the experimental manifestation of the generally accepted Parc-Ang damage criterion. Analytical formulas for the estimation of the remaining stiffness of structural members heavily damaged and deformed after blast occurring at their vicinity. Analytical formulas for the experimentally detected effect of temperature on the strength and deformability properties of the structural materials.

In case of a disaster (earthquake, explosion or fire) it can take several days for engineers to perform a rapid visual safety assessment and weeks before they complete a post-earthquake engineering analysis. During this time the owner and occupants are in a state of uncomfortable uncertainty about their safety . Moreover, immediately after an earthquake building stakeholders usually need an estimate of repair costs. To contract for and carry out a structural analysis and cost estimate of damaged building can require the stakeholders to wait weeks or months before reliable information is available. An automated assessment of the structural condition and repair cost could provide valuable preliminary information to owners, insurers, banks and public-relief entities to begin funding restoration efforts. Under operating conditions the most common reason for changes in the internal forces during the building life-span is differential settlement between foundations on cohesive soils subjected to consolidation. Early detection and repair of the resulting damage will result in a large decrease in repair cost because problems are less expensive to fix when they are first developing, prior to significant physical deterioration. A methodology is needed that, based on the results of monitoring devices, will assess the structural condition of the building; and, based on this, a methodology is needed that building managers can use for the formulation and justification of building repair costs. To directly assess the axial force and the bending moments in a cross-section, strain sensors are required at the three corners of the cross-section at the extremes of each structural member. Thus, a total of 6 sensors are required for each member, such as beam, column and shear wall. Therefore, for a structural system consisting of 'n' linear members, the required no. of sensors will be 8n. As an example, for the direct assessment of the internal forces in the members of a 6-story building with plan dimensions of 15x15 m2, to which correspond about 16 columns and 24 beams per story, the total no. of members being n=6(16+24)=240, the required no. of sensors will be 8x240=1920. The no. of required sensors has been dramatically reduced in this work because instead of aiming at a direct assessment of the internal forces in each member; some critical global parameters of the overall stress condition are being sought. Then, under operating conditions, the internal forces in each structural member as well as their structural adequacy and the differential settlement between foundations have been assessed through a finite element program that accepts as input the measured values of the above critical parameters. In this case strain sensors are only placed at the columns' bottom cross-section of the ground floor. In the case of the 16 columns of the 6 story building in the previous example, the no. of the required strain sensors is reduced to 6X4=64 sensors. A novel energy-based theory of seismic failure for R.C. members has been developed by the authors of this report at the plastic hinges developed at their end cross sections. In the previous version of this theory as applied in the MEMSCON Project, failure ensues at the locations of maximum bending moments where there is no shear. In this work, the above theory has been refined and extended to include shear.

**On the loss and needs module,** the delivered prototype features 1) a unified methodology for the assessment of economic loss and needs resulting from any of the extreme events under consideration (earthquake, blast/impact, fire) that can be extended to include additional extreme events; 2) the assessment of physical damage at the component and global level due to the extreme events under consideration and the assessment of the direct economic consequences of such damage; 3) a detailed taxonomy of all structural and non-structural components of a reinforced concrete building. This taxonomy provides naming of all components that are consistently used throughout the set of WP3 reports and 4) global collaboration by being consistent, as much as possible, with existing building taxonomies developed for national use (e.g., in the (US) ATC – 58 project) or for international use (e.g., the GEM building taxonomy.

For structural components: (a) in the case of seismic loading, the damage states are based on the damage index for the component, an input from the Structural Model in Task 3.2. The damage index of structural members is the ratio of the released internal bound energy over the available internal bound energy. This index and the resulting damage state are far more credible than present methods as they are based on the results of a detailed structural analysis permitted by sensor measurements in the monitored building. (b) In case of explosion there is an initial state where the air pressure generated by the explosion exerts on the structural members, mainly those lying in the vicinity of the explosive charge, a sudden transversal blast loading with duration of some milliseconds. As a result of this some of the structural members together with the associated non-structural components might reach a point beyond practicable repair. These structural members will be an input to this model. The no longer functioning structural members, together will all the non-structural members attached to them, will be part of the debris calculation in this work. Damage to the remaining components (structural and non-structural) will be due to blast induced vibrations and, thus, the damage states developed for, the similar, seismic vibrations are appropriate and have been used for this type of blast damage as well. (c) In case of fire the input from the structural model will be in the form of safety factors (S.F.s) for each structural component that will determine the need for intervention. Additional input from the structural model will include the midspan deflection in beams and temperatures that will determine the type of intervention. (d) In the case of operating loads the input from the structural model is in the form of S.F.s that determine the need for intervention.

For non-structural components, in the case of seismic or blast damage, the damage states are based on input (e.g., interstory drift, peak floor acceleration) from the Structural Model in Task 3.2. In case of fire, the damage states are based on input from the temperature sensors on time of exposure and maximum temperature. Emphasis has been placed on exterior, non load bearing, masonry walls, prevalent in r.c. buildings in the seismic prone countries of Europe and elsewhere (e.g., in Australia or New Zealand), because the assessed damage of these walls will be used to calibrate satellite based damage maps after an earthquake (WP4). Here, based on published experimental and analytical work on seismically damaged masonry walls and using input from the structural assessment in Task 3.2, the partners were able to assess, the seismic damage of these walls. The estimates of non-structural damage, economic loss and needs are continuously updated as estimates of physical damage of the structural system change with time (e.g., due to seismic aftershocks).

The developed methodology is able to give to building owners or managers, or insurance companies a first assessment of damages very soon after the event, taking into consideration the structural response of the building and the structural conditions of the construction components as they are emerging after the event. Calculations take into account the damage states of the building elements and the relevant repair actions. Loss and needs are assessed in terms of residual functionality of the building, cost estimation and required time for repair, calculation of generated debris The methodology is applied on both structural and non-structural components of the building on the basis of a taxonomical categorization, since it is generally accepted that costs relevant to non-structural elements exceed the value of structural components. The building model, based on the categorization of all the building components, is able to be integrated with the most advanced design and management technologies as Building Information Modelling (BIM).

**WP4** has focused on a state-of-the-art assessment of structural damage mapping using oblique airborne images, and definition of technical requirements and a methodological framework for integrating the actual image data, as well as geometric and thematic derivatives, with the sensor information and derived structural damage information. The focus of the WP4 work, has been on image-based gap detection and texture-based damage classification. The aim of this work has been to create 3D information from drone-acquired oblique images, to identify individual buildings in such data, as well as to identify structural gaps; and finally to determine that the previous findings (i.e. architectural gaps, or gaps due to disaster damage) are realistic. A methodology has been developed for building level automatic damage scoring by assessing the exterior damage evidences using the images captured by drones and the 3D point cloud information derived from them. Individual methods have been developed for 1) automatic detection of damage evidences such as debris/rubble piles and spalling from images, and 2) automatic 3D modelling of building from point cloud and images that facilitate to perform building-level comprehensive damage scoring. Moreover, image-based damage mapping has been improved through advanced machine-based learning (through convolutional neural networks). This proved to be a major advance, and the approach, while initially intended only intended for aerial/UAV images, as also tested on satellite imagery and found to be a viable way to identify structural damage. This demonstrate that since the drafting of the original RECONASS proposal that foresaw a calibration of damage maps derived from satellite imagery through the damage information obtained from UAV imagery, such calibration has become unnecessary. Instead of a limited and error-prone calibration now a direct damage assessment of satellite imagery is possible. Another focus of the was on conceptualising a sensor network extension, extending the utility of the RECONASS system to monitor for hazardous chemical exposures. In the following sections, the entirety of scientific and technological methods developed for remote sensing assessment is described.

**Development of methods to identify structural damage from oblique stereo-imagery acquired from an UAV.** This task includes various subtasks as listed below, 1) Development of automatic methods to identify the individual buildings in the scene in order to perform per building level damage assessment. A specific focus has been on the automatic detection and classification of structural openings/gaps as they appear in 3D data extracted from imagery. Those gaps are highly complex, and for several reasons can be normal and desired (e.g., architectural elements), or indicate damage. However, due to the 3D information generation process gaps can also be created in case of partial building occlusion (e.g., by vegetation) or image matching problems. Hence, we focused on the development of a methodology that can identify those different cases, leading to a reliable determination of openings due to structural damage. 2) Development of automatic methods to identify various kinds of damage evidences that are required to perform per building-level damage classification: The required damage evidences include debris/ rubble piles, spalling, broken elements, structural gaps that are created from damage, cracks and debris volume estimation.  The method for automatic identification of damage based structural gaps was developed. To the above context a common damage data dictionary has been created to ensure that all parties adhere to the same concepts of different damage elements and their specific expression and detectability, but a CAD model has been produced as a common geometric reference basis, to which both the internal and external damage will be associated. As part of the damage data dictionary and CAD model development it was realized that further discussions are needed on how best to relate objectively detected external physical damage with model structural and non-structural damage mapping results (by TECNIC and DBA). Likewise, when associating mapped damage with an abstracted CAD model, and one corresponding to the pre-disaster state, ambiguities are possible. For example, deformed façade elements may not be easily related to the original CAD model element.  The method for automatic detection of other damage evidences such as debris/ rubble piles and spalling was developed and is novel in the field of remote sensing-based damage classification. 3) Development of methodology for automatic 3D modelling of buildings from the structurally damaged urban scene using the images and the 3D point cloud derived from them: A semantic integration of different kinds of aforementioned damage evidences that have occurred at different positions of the building is a prerequisite to perform building-level damage scoring. The 3D modelling of a building is identified as the best representation to perform such semantic integration of damage evidences to infer the comprehensive damage state of the building. Also, this kind of 3D model is required to carry out the processes, which are discussed below. Thus, a novel methodology was developed for automatic 3D reconstruction of buildings from the UAV images and its derived 3D point cloud.  4) Development of framework for building level damage classification system for very detailed per building level damage assessment in a 3D perspective based on the aforementioned damage evidences and the 3D model of the building. On the development of automatic methods to identify various kinds of damage evidences that are required to perform per building-level damage classification the scenarios tested included the use of both pre- and post-event data, as well as post-event data only.  On the integration of remote sensing damage assessment into PCCDN tool, the main properties are: the building model is represented in the standardized IFC format. This format allows modelling the geometry of a building in detail, but also attaching attributes and semantics to the single parts. In RECONASS the building to be monitored is modelled beforehand and each relevant element is assigned a unique id. After data acquisition using the UAV (multiple vertical and oblique view images), an as-is documentation is possible. The retrieved block of images and derived point cloud gets automatically co-registered to the initial building model. After the subsequent damage mapping using the remotely taken images the observed damage evidence can be mapped to the single building elements. The result will be a 3-level damage indication per building part: 0: no visual damage, 1: visual damage, 2: destruction. This information is needed by structural engineers to verify the modelled and estimated damage. In addition further information is delivered in case of 1: visual damage: per element the following evidence is mapped (if observed): gaps, cracks, spalling, and inclination. This information will facilitate further (human based) damage assessment. Furthermore, detected debris and rubble piles will be delineated and the outline (as closed polygon) integrated into the PCCDN tool, as well.

**Development of a method to integrated satellite and airborne data based information for synoptic damage assessment - Development of validation and calibration procedures for the satellite damage maps:** The post-event high resolution satellite imagery usually made available within few hours after the event becomes an ideal data source for rapid assessment of damage over larger areas. Based on these images, numerous damage maps of different kinds with varying levels of information are produced by many agencies to aid emergency response actions. However, these maps are not necessarily reliable as they are not validated. Hence, it would be a critical and ambiguous process for a stake holder to identify a more accurate map. Moreover, these assessments are often found to be under- or over-estimated due to various reasons including image quality and inept mapper. Hence it was proposed in RECONASS to develop a suitable calibration process to improve the estimates. Since ground truth data are crucial for validation and calibration of these maps to make them more reliable and accurate but are expensive to acquire, it was proposed to analyse how the RECONASS-based local assessments of monitored and neighbouring buildings from UAV and sensors as ground truth data can be used for validation and calibration of the satellite-based damage maps. An initial framework for validation and calibration process was developed, and a range of experiments carried out. Nevertheless, the later advances on multi-perspective damage mapping with UAV data, in particular using advanced machine learning, led to a methodology that proved robust and reliable, and appeared to work directly on satellite imagery. This requires further testing (which fell outside the scope of RECONASS), but it suggests that a direct automated analysis of satellite imagery will yield more uniformly accurate results than locally calibrated maps.

**Multi-sensor synoptic damage assessment for different event types:** This includes three subtasks, 1) Synergistic use of image- and sensors-based assessment for 1) validation of the outcome of one technology with another; 2) image-based assessment as a proxy in case of any sensor information loss; 3) to improve the level of assessment by compensating the limitation in one technology with the strength of another: The major challenge with this task was the creation of meaningful interface for relating the image-based external damage to the sensor based damage information from the inside of the building. A geo-referenced CAD model framework has been proposed in which both the internal and external damage indicators can be referenced. The image-based 3D point cloud was co-registered with the CAD model, thereby the image-based assessment could be annotated to the 3D CAD model on which already the sensor-based damage information had been annotated. Hence, it was shown how both the image and sensor-based assessment could be related. 2) Development of methods to detect cracks and inclined elements: Using primarily the Sweden pilot data a method was developed to identify a range of damage types, including cracks, spalling, openings not part of the original design/construction. The analysis proved that the damage caused by the two blasts carried out in the pilot, including façade deformations, could be reliably and accurately detected. The scenarios tested included the use of both pre- and post event data, as well as post-event data only (see section 6 in D.4.3). 3) Integration of remote sensing damage assessment into PCCDN tool: In a coordinated effort, the partners RISA, DBA and TECNIC developed an interface to facilitate the data exchange between results obtained from WP4 to the PCCDN tool. The main properties are: the building model is represented in the standardized IFC format. This format allows modelling the geometry of a building in detail, but also attaching attributes and semantics to the single parts. In RECONASS the building to be monitored is modelled beforehand and each relevant element is assigned a unique id. After data acquisition using the UAV (multiple vertical and oblique view images), an as-is documentation is possible. The retrieved block of images and derived point cloud gets automatically co-registered to the initial building model. After the subsequent damage mapping using the remotely taken images the observed damage evidence can be mapped to the single building elements. The result will be a 3-level damage indication per building part: 0: no visual damage, 1: visual damage, 2: destruction. This information is needed by DBA and TECNIC to verify the modelled and estimated damage. In addition further information is delivered in case of 1: visual damage: per element the following evidence is mapped (if observed): gaps, cracks, spalling, and inclination. This information will facilitate further (human based) damage assessment. Furthermore, detected debris and rubble piles will be delineated and the outline (as closed polygon) integrated into the PCCDN tool, as well.

**Conceptualization of sensor network extension:** The RECONASS system was initially conceived to deal with threats from blasts and seismic activity. However, the current threat situation extends beyond those 2 hazards. It was therefore proposed to assess if the RECONASS system could assume additional tasks, specifically whether also biological and chemical threats could be monitored and detected. The nature of the task was purely conceptual, and no experiments were done. The work included a detailed review and assessment of existing threats that are relevant in the RECONASS context, as well as the state of the art of sensor technology to detect and measure those contaminations. The conceptualisation then proceeded with an assessment of which sensor types could best be incorporated in the system, and how. This included an analysis of how the system can be extended via adding fixed sensors to the monitored RECONASS building(s), but also how UAV-based sensors can be employed as part of the monitoring system. The review revealed that currently relevant biological threats, including pathogens and biotoxins, are not directly relevant for RECONASS, since their dispersion is either very local (through solid substances/powders) or though water networks. The review on chemical threats revealed that several agents in both the Toxic Industrial Chemicals and the Chemical Weapon Agents categories indeed pose relevant threats. The state of the art in sensor technology further revealed that for a range of chemical threats low-cost sensor options exist that are produce output that can readily be fed into the PCCDN tool, allowing both continuous monitoring and early warning.

**WP5** activities delivered **the PCCDN tool prototype**, a **multidisciplinary Information System for Crisis Response, Reconstruction & Recovery Planning**, acting as the intermediary between the monitoring system, the damage loss and needs assessment, the remote sensing and the Graphical User Interface the latter visualising the entirety of information to the end users. An open architecture was adopted and the implementation of the PCCDN produced the prototype of the Enterprise Service Bus, being the core entity of the overall platform that hosts the various senor services and the relevant data fusion to provide the end users with an intuitive building monitoring interface. Additionally, the entirety of sensor services (observation, alerting and tasking) have been implemented and tested in laboratory conditions. In parallel the graphical user interface has been developed and passed several iterations with the assistance of selected end users (including THW, being a RECONASS partner) to result in the most user-friendly form. Noteworthy, the RECONASS platform delivered to the end users features security measures that ensure authorized and unsusceptible access for nodes and users under any circumstances. The PCCDN tool prototype delivered has been extensively tested against the entire range of functionalities it offers in the full system integration tests. Subsequently, the tool has been deployed in the pilot demonstration for providing the ultimate assessment of the building under explosion stresses.

The **PCCDN Tool** is prototyped with the concept of SOA as a Cloud Service. Based on Wireless Sensor Networks (WSN), it combines web-based services and components, database systems, users, and WSNs. PCCDN users, be they NGOs, government agencies, humanitarian agencies or financial institutions are able to log into the system and retrieve information regarding an area of interest, which may have one or more facilities that are being monitored. The information includes recovery operation information, sensor data, satellite data, meteorological data, etc. The PCCDN is a software application that provides and uses web services. Using the SOA, software components are loosely coupled and they can be easily reused. A service can be consumed by various applications and operational processes. The benefits of this architectural style include the reusability of existing applications, and the interoperability between heterogeneous applications and technologies. Services are software components with a well-defined functionality as a contract. Service providers register the service in a registry. A client-consumer can find that service in the registry and consume it. The client is unaware of how the functionality offered by this service is implemented. Services can also be used to build composite services. Sensor data in the PCCDN tool are used by defining a Sensor Observation Service. This service is consumed by the sensors to feed the data into the system database. The service could be used by any sensor or application as long as it conforms to the defined service contract. The service will be also used by the sensor data fusion services of the system and the workflow controller. A SOA implemented via an ESB is determined by a layered architecture, consisting basically of a resource, service, orchestration and application layer. Services are orchestrated to execute specific processes of the application domain. The services are interoperable and follow principles, such as service contract, loose coupling, abstraction, reusability, autonomy, statelessness, discoverability and composability. The implementation is based on implementation of sensors data services solution provided by 52° North. The provided solution is the most complete in comparison with others because of the support of the three services (Sensor Observation service, Sensor Event Service and Sensor Planning Service). The deployment in an OSGi environment was a challenging task, due to the heavy use of ClassLoaders within the 52° North implementation and we had to reform dependencies of bundles. The XMLBeans technology is used for accessing XML by binding it to Java types but we do not use the official xmlbeans release dependency but an OSGi-enabled repackage from Apache ServiceMix. The PCCDN tool uses Sensor Observation Services (SOS) to insert, update, get or delete sensors and sensor data. Sensors in RECONASS include accelerometers, strain sensors, local positioning sensors and temperature sensors. The service is consumed by the sensors to feed the data into the system database. Besides that, it is used for retrieving sensor data and sensor information. The service could be used by any sensor or application as long as it conforms to the defined service contract. The service will be also used by the sensor data fusion services of the system and the workflow controller. The Sensor Event Service (SES) provides a subscribe-based access to sensor data. It also provides methods to register or delete a network, add or delete sensors and send notifications to the service. The PCCDN tool provides Sensor Planning Services that implement the OGC Sensor Planning Service Implementation Standard. The standard is also part of the OGC Sensor Web Enablement (SWE) suite of standards and defines interfaces for queries that provide information about the capabilities of a sensor and how to task the sensor. The implementation is based on the 52North implementation. The goal of the standard is to standardize the interoperability between a client and a server collection management environment. Regarding **the data fusion implementation**, the JDL fusion framework has been used within the RECONASS software, to generate the sensor data fusion services. The JDL model is divided in various processes not necessarily to be implemented, useful for the system design. In level 0, all the pre-processing of sensor measurements takes place. In level 1, "object refinement" determines the identity and other attributes of entities. Situation refinement in level 2, fuses the spatial and temporal relationships between entities while in level 3 'enemy forces' are fused to assess the thread that they pose. Level 4, not part of the core level, is related to resource management and refinement. The purpose of using data fusion is to gather reliable information in order to support decision making. Algorithms for the combination of sensor measurements from different data sources and sensor types create the input dataset for the further processing steps; in RECONASS case, structural assessment damage. In regards to **Workflow orchestration and Service registries**, their implementation are an important step in moving towards managing the complexity of information and act as a middleware for a distributed service oriented infrastructure. The provider of a service creates a web service and publishes its access information to the service registry. The service consumer searches the broker registry (with the use of find filters) and after locating the web service of interest, binds to the service provider in order to invoke it. Apache jUDDI has been chosen for creating the service registry. Apache jUDDI is server and client-side implementation of the UDDI v3 specification. UDDI is an initiative by OASIS (Organization for the Advancement of Structured Information Standards), for enabling businesses to publish service listings and discover each other over the Internet. The provider of a service creates a web service and publishes its access information to the service registry. A specific data model is used to represent entities in UDDI. Moreover, a self-organizing service workflow controller has been created to manage the real-time registration and tasking of sensor observation services and fusion processing services. Sensor data services (SOS, SES and SPS) and sensor fusion services will be orchestrated to create high level processed data suitable for visualization and situation assessment for the monitored facilities. SOS, SES and SPS are coupled together to create an integrated solution for the registration, discovery and access of heterogeneous and distributed sensors. Data fusion services are used to extract and combine information from sensor services to meet the requirement of creating input datasets for the processing steps of the PCCDN tool. The PCCDN tool can be continuously fed with information: a) from the wireless sensors (strain, accelerometers, positioning tags and temperature sensors), b) from the monitoring–based structural assessment module on the damage state of the structural elements and the overall structure, c) from the damage, loss and needs assessment module on repair needs, debris and functionality in the case of non-structural components, d) from the remote sensing based structural damage assessment module on collapsed and intact buildings in the scene, presence of damage evidences, debris and rubble piles around the building, and e) the PCCDN tool will be extended to receive additional information, such as input from disaster management agencies, and meteorological data.

The workflow of information within the system follow the below logical approach: Under operating conditions, the structural condition of the monitored facility is periodically assessed. Sensor fusion services create the input dataset of strain measurements for the structural assessment module. The assessment data (differential displacements, live loads and safety factors) are fed into the PCCDN tool and become available to the user. In case of an earthquake, an alert event is produced and acceleration data connected to the event are fused to create the input dataset for the structural module. The results are available to the user. In case of an explosion relevant positioning tags input is provided to the positioning tag correlation module. The PCCDN tool receives the estimated differential displacements and combines it with relevant acceleration data to provide the structural assessment module with input for further assessment. Similarly, in case of a fire, an alarm is created for the SES. The PCCDN tool, subscribed to alerts will respond by invoking the corresponding assessment function. For any type of type of event, the workflow controller uses the structural assessment information (damage indexes) as an input dataset for the Damage, Loss and Needs Assessment module. The results of the module are available to the authorized user of the system from the user interface. The calculated or estimated damage state of the structural assessment and the damage, loss and needs assessment module serves as an input for the remote sensing based structural damage assessment module. This module provides the end user of the system with UAV images of the structure, damage evidences and debris information. **On the User Interface**, the prototype provides a graphical environment through which the end user can retrieve current and historical data from database. Additionally it provides visualization of the results calculated by other modules in a textual and graphical manner. Emphasis was laid on four aspects regarding the design of the user interface: a) Ease of use - all users should be able to reach effectiveness and ease of use without any particular training. B) Guidance - the user should be able to find his way in the interface with minimum effort, achieving easy and correct use of commands, thus increasing reliability and effectiveness of use. c) Error anticipation and prevention - All users (even experienced ones) inevitably make mistakes. A proficient system should be able to guide the users for the easy and correct use of its commands so as to avoid errors. However, in the case of error the system should be able to deal with it effectively, issue the appropriate error-message and avoid disruption of the operation. D) Integration - the PCDN tool consists of separate components which communicate via web services. It is important for efficiency and effectiveness of use that the user should be able to work in a conceptually unique and coherent environment, handling transparently inter-module communication via appropriate mechanisms and operating system calls. Moreover, interaction with the user should be avoided if execution of operations could be achieved without any user input. The design and implementation of the PCCDN prototype enables the management of complex and distributed information and processes in order to respond effectively to the user needs. Services are published in the service registry that aims at managing the complexity of the system resources. In workflow orchestration, processing services integrate sensor data and the results obtained by other RECONASS modules. The user interface provides results in a textual and graphical manner.

WP6 on System Integration ties together the entirety of the RECONASS components to result **the integrated RECONASS system**. Significant progress has been realised since a miniaturised instance of the overall system has been integrated in a controlled environment supporting the basic functionalities that RECONASS should meet (aggregation of sensor measurements, interface hand over, end to end values exchange and insertion to the assessment modules to name a few). Noteworthy, casing of the sensors has been finalised and the relevant assembly has been performed. Towards the end of the integration work package, integration workshops were held to perform end to end tests of the system, prior to full system tests the pilot demonstration. These integration workshops proved a very successful method of test and identifying opportunities for improvements. During integration the system was tested against the requirements identified in the previous work packages. As RECONASS aims to provide a monitoring system for constructed facilities that will provide a near real time, reliable and continuously updated assessment of the structural condition of the monitored facilities after a natural or manmade disaster, **a sophisticated and seamlessly integrated system has been delivered.**

RECONASS has developed small, inexpensive, wireless, local positioning tags that are embedded in the structural elements of the monitored buildings to report their position to the base station. The wireless local positioning tags measure the displacement of structural elements using radio frequency signals. They are connected to the RECONASS Data Collection Hubs via a Zigbee module. Following a disaster, comparison of the original position of the tags – in the undamaged state – with the final position of the tags – in the damaged state – is used in order to hypothesize the structural system that has emerged from the disaster. The system can then be used to assess the structural response, damage and loss. At elevated temperatures the properties of the materials used to construct the building can be begin to degrade. For this reason temperature sensors are embedded into the structure of the building. The temperatures within the building are monitored by the system. The temperature sensor provides analogue voltage output proportional to the temperature it measures. The temperature is converted from analogue to digital and then passed to the data hubs via Zigbee. In testing, battery powered temperature sensors were used since during blast scenarios independent power system should actively support sensor operation. Two types, physically wired and wireless types have been tested. During a collapse event structural members of the building may be subject to excessive loads. To monitor these loads during and after such an event, the building is equipped with embedded strain gauge sensors. These strain gauges will indicate the changes in strain that the structural members have been subjected to. Strain modules essentially consist of excitation voltage supply, bridge completion modules with strain gauges. These provide analogue voltage proportional to the strain a structure undergoes. The communication sensor modules are waspmotes that communicate with the data hubs, namely the data aggregators. The structural strain is converted from analogue to digital and then passed to the data hubs via Zigbee. The former two modules act as a wireless sensor node that remotely communicates with the data hub. This arrangement particularly suits to building monitoring as each strain node works independently thereby making it possible to mimic events such as earthquake or blast or fire scenarios. This is relatively low cost option to assess building integrity. The wireless sensor nodes are mounted in an ABS box, which can be attached to any wall, beams or columns of the building. The scope of this design is to allow ease of assembly of modules in a building of interest. Acceleration sensors are embedded within the system to assess the magnitude and direction of any movement caused by an event. The Accelerometers measure the acceleration at the various parts of the building or structure subjected during an event. The acceleration magnitude is passed to the data hubs. To ensure that the positioning, acceleration, strain and temperature information from the monitored buildings can reach the base station, a gateway-tool for communication provides redundancy at situations of access network unavailability by utilizing multiple and different access interfaces, e.g., GSM, UMTS, ADSL connections etc. Data Collection Hubs connect the sensors to the Communication Gateway. All of the information from all of the sensors is passed through these hubs to the Gateway. The Communication Gateway holds a central position in the system architecture of RECONASS being one of its core modules. The primary functionalities that the gateway has to conform with are as follows: a) Reception of sensor related information (metadata and measurements) from the heterogeneous sensor networks. This information is collected via the data hubs; b) Management of the heterogeneous sensor networks for optimum performance and intermittent operation (sensor network status, automated and on demand measurements collection, reconfiguration of sensors, tec.) This function is realised via exchanging commands with the data hubs; c) Connection and information exchange (sensor, interface and alerts related) with the PCCDN tool using a dedicated virtual private network (VPN). The UAV performs a detailed damage assessment along exterior elements of the building using remote sensing images. These images will be fed as an input for the RECONASS system. Remote sensing-based damage maps are provided, using both air- and space-borne imagery. Near real-time construction damage data from the monitored buildings are used in order to effectively calibrate and evaluate these maps. The needs of the monitored buildings are continuously updated with space-borne and airborne damage maps (calibrated and validated for the buildings monitored) in a much reduced time, fused and integrated Based on this, the PCCDN Tool provides the recovery stake-holders with near real-time, detailed and reliable data and information on the construction damage and loss. This Tool will provide international interoperability to allow for customization, expansion and permit collaborative work between the civil agencies/authorities and the relief units. The PCCDN tool takes all sensor and UAV information which has been stored in the cloud (remote database) by the gateway tool and com-bines it other information to determine the structural damage and deduce the post crisis needs. Disparate application components, independent of programming languages and running platforms need to be independently developed, yet easily integrated into to the PCCDN. External sources include the monitoring system, the structural assessment module, the position-ing tag correlation, the loss and needs assessment module, the remote sensing assessment module, external alerts/information. Sensors' information and observations are inserted/retrieved in/from the PCCDN database with the use of OGC compliant Sensor Observation Services (SOS) services. Special procedures are followed to store and retrieve information from each of the calculation modules Wireless network interfaces and Ethernet wires are the final components required for the system to be integrated and fully operational.

**WP7** deals with the RECONASS evaluation phase, focusing in parallel on preliminary demonstration and table top exercises as well as on component and structural testing. The final steps of the evaluation concern the large demonstration activities where the RECONASS Integrated system has been installed in a 1:1 scale, 3 storey building, the latter subjected in external and internal explosions. Noteworthy, the pilot demonstration and a series of workshops have been exploited for interacting with potential users of the system and receiving feedback on the performance of RECONASS for its final evaluation.

The overall goal of the **component testing** was to get as much knowledge as possible to support the design of the large pilot test at the end of the project. Moreover, it gave opportunity for the sensor development process to test the equipment for durability against blast impact. By starting off with simple structural parts in scale and compare it with finite element analyses cost effective and confident experimental results was attained. The results from the finite element analyses in RECONASS show good agreement with the obtained measurement data for the structural response of both single slabs and the multi-node structure. With these tests and simulations we have received useful knowledge to perform the outer detonation in the final pilot test in Älvdalen. The component tests were monitored by high-end recording system with gauges able to capture the explosion effects. With these results the other project partners have a good set of data to design their different gauges and recording equipment to be used in the pilot test. The durability tests also gave input to the sensor developers which will has been taken into account in the design of the equipment.

The aim of the **pilot test** has been to experimentally evaluate: a) The gauges and equipment newly- or further developed in the RECONASS project, b) The theory for the assessment of the structural condition of the structure that has emerged from the disaster of an explosion, c) The non-structural damage assessment developed in WP3, d) The whole RECONASS system in a test simulating a terrorist attack. The following results have been obtained.

On the PCCDN tool, it managed to collect and process the data and all data on the Gateway were replicated within the tool. No data were lost in the transfer. On the remote sensing system, the use of UAV images taken before and after an event a damage evidence detection method was developed. Of course it only detect visible damages and not building element inside a building. Severe cracks were probably not detectable either although spalling was. The input to the PCCDN tool performed well and gave valuable results. On the Damage assessment tool, the VEBE code corresponded well to the actual test result. The structural assessment module using the non-linear elastoplastic analysis gave accurate output compared to the actual outcome of the test. For the internal detonation the structural model of the building was modified. Here the model used for validation purposes the surveying measurements made after the explosion. This system only considered the permanent deformation to estimate the damage. A building element could very likely been subjected to a large displacement under a very short duration but with very little permanent deformation. The strength of this element after a detonation could be very low. Today's building code demands redundancy concerning bearing wall or columns, to prevent progressive failure of buildings with several stories. So for an external detonation, which actually give a rather concentrated damage to the bearing parts of the structure, the assessment tool probably will estimate the rest of the building rather good. In the case with an internal detonation the case might deteriorate. One charge could, if placed at the "right" spot, actually take out more than one bearing wall and create a progressive failure. One may also say that a small final deformation with a large deformation history is rare but not unlikely. In most cases you get a collapse and the assessment tool will detect. To identify the building status after a detonation these building elements should be dealt with separately. The non-structural assessment module was compared to a visual inspection. Mainly the first external detonation was analysed that caused debris. The module performed well compared with visual inspection. Moreover the communication gateway performed well as it captured and subsequently transmitted to the PCCDN tool all data generated by the sensors.

On the **evaluation process** and results of the integrated RECONASS system two means have been utilised: a) the final end-user workshop at the ISCRAM 2017 conference in Albi during which a final evaluation sessions was held as the workshop gathered a large variety of representatives address the entirety of the RECONASS end user group types and b) the functional tests of the final integrated RECONASS system in the constructed building in Sweden. However, during the whole RECONASS project, end users were consulted to create a user requirement driven system. At the end of the project, end users were involved again to evaluate the achieved RECONASS system. The evaluation process focuses on the evaluation of non-functional requirements and the results of the end user participation in the project. After presentation of the integrated system in the third end user workshop, end users focused on the functional suitability, usability and reliability of the system. The vast majority of consulted end users were impressed by the functionality of the system. The majority of the discussions concerned the next necessary steps to implement such systems in pilot buildings to gather operational experience. Cost aspects played an important role for the end users. Further developments such as the development of mobile apps to interact with the system were also encouraged.

### 4.1.4 Potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and the exploitation of results

#### *4.1.4.1 Potential impact (including the socio-economic impact and the wider societal implications of the project so far)*

RECONASS main outcome, namely the delivery of a multidisciplinary Information System for Crisis Response, Reconstruction & Recovery Planning (the PCCDN tools, sensors, communication systems and building assessment software) for constructed facilities reaches a wide applicability at an EU level and provides important enhancements at the service of Civil Protection and Crisis Management. RECONASS main targets upgrading post-crisis activities in the Recovery phase however the overall system may be operational during Preparedness and Response. The following high level potential impacts evidence usability and crisis functions of RECONASS:

- When RECONASS is monitoring a disaster affected building, relief organizations can begin funding restoration efforts at a much earlier date;
- During Response and Reconstruction phases Emergency Response crews will receive critical information promptly to pinpoint danger and in turn respond in precision;
- When RECONASS is monitoring a disaster affected building, disaster cost is to be reduced by preventing monitored structures from collapsing;
- Knowing functionality of Critical Buildings immediately after the disaster enhances asset utilisation;
- By RECONASS operates, all major recovery stakeholders using it will acquire a common picture of the situation;
- Preparedness may be enhanced, as the RECONASS system may act a simulation software;
- By using RECONASS system in critical buildings, early, effective handling of the reconstruction and recovery process will have long term financial repercussions.

Since project conceptualisation, 11 high level objectives/Expected final results have been foreseen that drove the entire work implementation from idea to delivery throughout the 42 moths of project duration. As explained previously the entirety of project objectives have been accomplished and delivered, hence in the following we report on high level accomplishments and their potential impact (including the socio-economic impact and the wider societal implications of the project so far). By successfully delivering the high level objectives, RECONASS may claim on achieving a wide site of associated potential impacts as per below.

1. RECONASS successfully analysed the state-of-the-art in regards to post-crisis damage and needs assessment tools and their deficiencies as well as accurately captured the needs of a wide stakeholders group to subsequently deliver a novel structural monitoring/assessment system
2. RECONASS produced a monitoring/assessment system comprised of inter-communicating sensors (tags, accelerometers, strain sensors, temperature sensors), remote sensing methods (aerial & satellite), assessment modules and PCCDN tool

**Related potential impacts:**

By successfully delivering the above high level objective, RECONASS may claim on achieving a wide site of associated potential impacts as per below.

- Stimulation of innovation in structural health monitoring is achieved in the EU and beyond.
- Creation of a database/inventory with lessons learnt to boost creation of reliable structural health monitoring systems
- Safer operation of buildings (incl. critical infrastructures) when RECONASS system is installed, with reduced and more targeted assessments

- Reduced costs for buildings' inspection and assessment when RECONASS system is installed (as it replaces both the initial and in-depth on-site structural assessment)
- High value facilities (as a target for terrorist attacks or governmental buildings in earthquake prone countries) can be monitored with the RECONASS monitoring system limiting downtime costs and enabling prevention
- Increased competitiveness of structural health monitoring industry by speedy and reliable assessments
- RECONASS improves reconstruction and recovery capabilities by providing relief units with an interoperable tool that is faster and technologically improved as available today
- Increased citizens' safety is achieved via enablement of safer buildings
- RECONASS delivered new and improved capabilities for users (rapid structural assessment of buildings, common operational picture when disaster occurs in a cross-organisational context, less aiming at strengthening competitiveness
- Relief organizations, insurers and banks can begin funding restoration efforts at a much earlier date
- Reconstruction activities may start earlier
- Since RECONASS provides a near real time assessment of critical buildings, after large scale disasters, it will be easier to obtain international financing soon after the disaster when the disaster is still in the news
- Emergency response crews will be provided with critical and timely information on damage in monitored facilities so that danger can be pinpointed and emergency response directed with precision
- Disaster cost will be reduced by preventing monitored structures from collapsing to limit damage to adjacent structures and additional loss of life when explosive devices impact highly populated urban centres
- Disaster costs will also be reduced when providing shoring to weakened monitored buildings to protect them from the aftershock sequence
- Safety will be promoted when dangerous monitored buildings or portions thereof will be demolished
- Knowledge of the structural condition of monitored buildings will reduce likely building-closure durations and consequently business interruption costs
- Identification of the safe monitored buildings for immediate use will help the government find the physical infrastructure needed to provide essential services
- Knowing the functionality of critical buildings ( such as hospitals) immediately after the disaster will help the government direct injured victims to available facilities
- RECONASS information to all major recovery stakeholders (in the form that they need it) will help them acquire a common picture of the situation
- Use of the RECONASS system will provide better situational awareness in case of any disastrous event helping to save lives, environment and culture
- Effective handling of recovery from a very early date will help increase the level of confidence to the government which can have economic implications, e.g., in the case of tourism
- Early, effective handling of the reconstruction and recovery process will have long term financial repercussions

**3.** RECONASS delivered an indoor, automated, real-time, wireless, local positioning system that provides information on the precise 3D localization of tags embedded in the structural elements of a reinforced concrete building

**Related potential impacts:**

- RECONASS will promote a European leading position in this market which gains momentum over the last years in various application domains (aside security, in logistics, transport, etc.)
- Extensions of the RECONASS LPS can be applied to other indoor services (e.g. airports' assets, moving objects, etc.)
- To advance the SotA in the indoor LPS domain (RECONASS delivered 3 D accuracies of around 10 cm for distances of up to 50 m in environments with strong multipath propagation)

- The RECONAS LPS approach may be applied to other disaster causes (tsunamis, landslides) in relation to structural health monitoring
- Decrease investment capital for costly positioning applications (e.g. containers tracking in yards, warehouses) utilising the low cost RECONASS tags

**4.** RECONASS specified the location of localisation tags to be embedded in the structural elements of an undamaged structure resulting to optimum assessment after a disaster

**Related potential impacts:**

- To result in speedy, calibrated and precise assessment for instrumented facilities after a disaster
- To enhance methodologies of predicting positions of buildings' structural elements
- To pave the way for alternative means of predicting position of structural elements
- To produce new assessment techniques

**5.** RECONASS assessed the residual strength of the structural elements and the structural condition and safety of the structure that has emerged from the disaster (in pilot demonstration when a 1:1 scale 3 storey building was monitored by RECONASS and there were executed an external and an internal blast).

**Related potential impacts:**

- To enhance methodologies of predicting residual strength of buildings' structural elements
- To extend residual strength monitoring to other materials and structures (steel, bridges, etc.)

**6.** RECONASS developed a method and the corresponding software implementation for the automatic assessment of direct economic loss due to structural and non-structural damage, building functionality, volume of debris, the duration of repairs and the resulting needs in manpower and materials following a seismic, blast and/or impact loading or fire in a monitored building

**Related potential impacts** (Points of Obj. 1 also apply)**:**

- RECONASS provided know-how on associating structural damage with economic restoration/reconstruction investments through novel methodologies and subsequent software implementation

**7.** RECONASS designed and prototyped a robust, resilient, seamless and interoperable communication platform that aggregates, processes and transfers under any circumstances the sensorial data to the assessment modules over heterogeneous networks

**Related potential impacts:**

- Work in this domain promotes SotA in the below technological areas:
    - Heterogeneous networks interoperability and interworking
    - Cooperative local area network technologies for improving data transfer
    - Self healing and extendable wireless sensor networks
- The communication prototype may be utilised to other security related applications (command and control centres, sensor networks for situational awareness) since development features an open architecture and utilises various communication networks (infrastructure based and infrastructure less)

**8.** RECONASS used sensor-based damage assessment of the monitored buildings for the calibration and validation of remote sensing methods

**Related potential impacts:**

- RECONASS demonstrates convergence of two different assessment methods enhancing precision of the remote sensing one
- It promotes SotA for remote sensing methods given the fact that terrestrial sensorial information may be used
- To extend remote sensing in other facilities and materials, again, converging with sensorial devices' outputs
- To promote such beneficial usage of UAVs in the future aiding at receiving the necessary legislative and protective measures at a European level

**9.** RECONASS developed and prototyped the RECONASS back-end, a Post-Crisis Needs Assessment Tool in regards to Construction Damage and related Needs (PCCDN) that provides the recovery stakeholders with near real-time, detailed and reliable data and information in the form that each one of the stakeholders needs it, on structural and non-structural damage, shoring and demolition needs, loss of functionality, direct economic loss and the resulting needs in construction manpower and materials of monitored buildings that will be continuously updated (due to, for instance, foreshocks, main shocks and the subsequent aftershock sequences in case of an earthquake).

**Related potential impacts** (Points of Obj. 1 also apply):

- RECONASS information to all major recovery stakeholders (in the form that they need it) helps them acquire a common picture of the situation
- To apply PPCDN to other structural health monitoring domains (bridges, aircrafts, tunnels, etc.)
- To form an inventory of buildings' capabilities at a National and at a European level
- To allow for liaison of additional platforms through open architecture implementation (e.g. public warning systems, civil protection modules, etc.)

**10.** RECONASS tested, validated, benchmarked and evaluated the above system in both a component basis as well as a whole in testing full scale structural nodes and in a 1:1 scale demonstrator within a three story r.c. building considering realistic scenarios (e.g. earthquake, terrorist attack)

**Related potential impacts:**

- RECONASS proving the assessment preciseness, reliability and robustness offered by the monitoring system
- Allowed for optimisation of the system through extensive evaluation of results and methodologies used
- To showcase European initiatives/projects for response and recovery after disasters through dissemination of demonstrator
- To allow for investigating extended usages of the RECONASS system through real data retrieved form actual building demolition

**11.** RECONASS provided a conceptualization of how the sensor-equipped buildings can be used to create a separate sensor network to detect additional threats

**Related potential impacts:**

- To allow for extension of applications derived from additional sensors and their data (e.g. IoT applications for security and welfare)
- To promote and enhance SotA of sensor networks

#### 4.1.4.2 Main dissemination activities

Public awareness activities aimed to spread the information about the project to the broad community to set the ground for exploitation of the results or possible technology transfer. Major awareness/communication and dissemination activities included: Project public website, Six-monthly newsletters, Social networks to communicate with larger audiences (Twitter and LinkedIn), Videos showing the RECONASS system at work at YouTube, Press releases, Presentation of RECONASS at the TV news, RECONASS leaflet and poster, Presentation of the results to the public at large, Project workshops , Presentations/ scientific publications , Formation of a group of external experts to assure the project's technical solutions are properly addressing the requirements from the emergency/disaster response organisations, building managers, companies offering structural monitoring services and organisations involved in the development of remote sensing based damage maps and to increase the deployability and acceptance of the RECONASS solutions., Communication with the European Civil Protection Agencies., News releases to Alpha Galileo and the Technology Marketplace., Interview given to Horizon-The EU Research and Innovation magazine.

**RECONASS Website:**

A project website (www.reconass.eu) has been developed in order to disseminate the project outcomes; it includes project objectives and background, significant achievements, technology news, consortium contacts, scientific publications and presentations, etc.

**Project Newsletters:**

Six newsletters have been produced that depict the project's main outcomes together with dissemination activities and upcoming events related to the project itself. (http://reconass.eu/index.php/media-centre/2013-05-31-13-17-15)

**Social Networks:**

The Twitter account is https://twitter.com/reconass, while the LinkedIn group that has been established is named http://www.linkedin.com/groups?grid=7446987. The links to the social media are available in all website pages.

**Demonstration Video of the RECONASS System:**

A video has been produced to promote in common (non-technical) language the RECONASS system and can be seen at the following address: https://www.youtube.com/watch?v=78UjdoktUWA&t=31s SHOX is the brand name of the developed RECONASS system for commercialisation purposes.

**Press Releases and Radio/TV Interviews:**

As part of the dissemination activities of RECONASS the consortium put special emphasis on the pilot test's visibility. As a result the RECONASS pilot featured in the Swedish news as follows:

The RECONASS pilot test appeared in the Swedish STV Channel News on 25/8/2016. The videos are available on the project website (http://reconass.eu/index.php/media-centre/reconass-pilot-test-external-explosion & http://reconass.eu/index.php/media-centre/pilot-test-internal-explosion) as well as on YouTube (https://youtu.be/te_gcKX36kY and https://youtu.be/LD7-B4NGmVU). The RECONASS pilot test also appeared in the Swedish TV4 News on 25/8/2016.

**RECONASSS Leaflet and Poster:**

A leaflet covering the projects' concept and objectives was produced in September 2014 to announce the project, which was aimed at distribution at all relevant key events to all the key target audiences.

A roll-up poster was produced at the same time to be used at all events to promote the project. This poster took the core content from the leaflet and present it in a more summarised and succinct way.

The leaflet and the poster can be downloaded following the link: http://reconass.eu/index.php/media-centre/2013-05-31-13-22-20

**Lectures to the public:**

Prof. N. Kerle (University of Twente) presented 2 lectures to the public as follows:

1) 30 September 2016: Twente Science Night. Topic: Safe & secure https://www.utwente.nl/bms/sg/temp/science-night/

https://www.utwente.nl/evenementen/!/2017/2/225170/studium-generale-drones

2) 28 February 2017: Part of the so-called Studium Generale where there were about 50 people of the generation 60+ https://vimeo.com/207306539.

On Friday 3rd of February 2017, Mr. Evangelos Sdongos, being the day-to-day project manager of RECONASS and an Assistant Researcher at ICCS-National Technical University of Athens, held a 2-hour undergraduate course on novel technologies for disaster management.

**RECONASS Workshops:**

The 1st RECONASS End-Users Workshop was successfully realised in Berlin on 24th – 25th of March 2014 (organised by THW) in which approximately 14 end users participated, as well as the majority of RECONASS partners. The end-users included Emergency/Disaster Response Organisations, public operators of critical buildings and organisations involved in the development of remote sensing based damage maps.

The 2nd RECONASS End Users Workshop was realized in M29 in Wessel, Germany, at the training grounds of THW. From June 22 through June 23, 2016, THW operating personnel, as well as fire fighters and ministry representatives from Germany, France, Italy, The Netherlands and Greece, had the opportunity to experience a live demonstration of the RECONASS system. In order to be able to observe the advantages or complementary qualities of this system THW presented the mobile construction monitoring system it currently uses. The guest experts were able to ask questions on the spot and were later asked to give feedback on how relevant RECONASS could be for their daily operative work. Moreover, this workshop gave a good opportunity to train THW and external end users on RECONASS, as well as to receive their invaluable feedback on RECONASS services. Another vital goal of the workshop was to exploit RECONASS face to face with potential future users and to introduce the new exploitation strategy and the new brand SHOX. Thirty six persons participated in the above workshop, including 4 people from fire services and 12 people from civil protection agencies.

The partners decided to organize the Final RECONASS Workshop in conjunction with an international event of the disaster management community in order to reach a wider audience and enhance the impact of the results. To this end RECONASS (together with the project INACHUS) have been accepted to chair a track and organize a Workshop on 'Post-Crisis Damage and Needs Assessment of Buildings for Response, Reconstruction and Recovery Planning' under ISCRAM 2017 (https://iscram2017.mines-albi.fr/). The aims of this workshop were to: present the project results after the successful pilot in Sweden; receive user feedback on the approaches followed; help identify useful refinements/extensions of the system and its components; discuss the importance and trends in Structural Health Monitoring in buildings as a means to avoid partial or total collapse when disastrous events take place (e.g., earthquakes, explosions). The workshop was a success including 19 people outside the RECONASS consortium that came from civil protection, disaster risk management, situation monitoring, Red Cross, fire brigades, research groups, industries and users. The participants commented that it is very useful that the RECONASS system is interoperable and that provides the capability of integration with first responders' applications. Recovery stakeholders stressed the need for a standardized format for exchanging emergency alerts (e.g. OASIS CAP) that was not foreseen in RECONASS.

**Presentations in Fora/Events/Conferences related to Disaster Management and Civil Protection:**

The RECONASS consortium was invited to join a workshop initiated by the BERISUAS cluster in Woensdrecht, Netherlands, on November 6, 2014 (http://www.mirg.eu/wp-content/uploads/2014/10/Berisuas-draft-program-.pdf).

- by THW in the framework of the 10th European Congress on Civil Protection on September 9th and 10th, 2014, in Bonn, Germany, which is a specialized congress for disaster management.

- by ICCS (through a joint roll-up banner with projects ROBO-SPECT and INACHUS) at the BSSAR 2014 event (http://bssar.kemea-research.gr/).

- by ITC at eRIC 2016 (http://www.exploric.nl/nl/partners/sponsoren/twente-safety-campus) in The Netherlands, through a brochure and slides.

**Scientific Publications:**

A total of 31 scientific publications have been realised through RECONASS implementation (6 peer-reviewd Journals, 24 scientific peer-reviewed papers, and 1 Book chapter). Please mind that RECONASS technical work is continuing to sustain scientific publication after the end of the project as more than 5 publications are, at the time of writing, under review.

**RECONASS Group of Experts:**

The following group of outside experts has been established in order to discuss with project participants the validity of results, challenges, promotion of the work to potential users, standardisation, and benchmarking, economic and legal issues. Dr. Axel Strobel, Bosch Sensortec, Germany, Positioning Systems Operating with Microwave Signals; Dr Nassos Anastasopoulos, MISTRAS Group Hellas, Greece, Integrated Sensing Solutions for Monitoring of Facilities; Prof. Daniele Zonta, University of Trento, Italy, Monitoring Based Assessment of Constructed Facilities; Prof. Stefan Hinz, Institute of photogrammetry, Karlsruhe Institute of Technology, Germany, 3D Modelling, Photogrammetry and Disaster Response; Prof. Vassilis Katos, Computing and Informatics, Bournemouth University, UK, Secure Communication, Interoperability; Dr Sotiris Lenas, Information Security and Incident Response Research Unit, Democretus University, Greece, Secure Communication, Interoperability; Dr Alberto Roncagliam, Consiglio Nationalle delle Richerche (CNR), Italy, Sensors for structural monitoring; Prof. Apostolos Sarris, Foundation for Research and Technology Hellas (FORTH), Greece, Remote Sensing

The RECONASS Consortium would like to thank our experts for their continuing support throughout the project implementation.

**Communication with the European Civil Protection Agencies or Departments:**

The partners have contacted via email the Civil Protection Agencies or Departments in **all** European countries (e.g., the Federal Office of Civil Protection and Disaster Assistance in Germany, the national Crisis Centre, Directorate General of Public Order and Safety in The Netherlands or the Ministry of Jus-tice and the police in Norway) and provided them with information on RECONASS, thus reinforcing awareness on RECONASS results and capabilities in the user domain.

**Interview to HORIZON - The EU Research and Innovation Magazine:**

On May, 2016 issue of Horizon - The EU Research and Innovation Magazine, includes an interview given by Dr A. Amditis on RECONASS with the title 'Quake, Storm or Fire? Airborne Tech is Coming to Rescue.' Exploitation of results

#### *4.1.4.3 Exploitation of results*

RECONASS showcases a wide set of exploitation activities, witnessing the great potential of the system's commercialisation. In this section we present and briefly discuss achievements reached from an exploitation perspective. Noteworthy, at the end of the project and as the RECONASS consortium has been approach by a large construction firm, namely Arabtec Consolidated Contractors Ltd, on submitting an offer regarding the RECONASS monitoring system, the Consortium works on next stages addressing the creation of a joint venture/spin-off company that concerns the RECONASS Project's prototyped monitoring system.

**IPRs of the Consortium Members:**

The RECONASS system as a whole is considered of asset to the entire consortium. However as it comprises of the sub-systems we provide below its building blocks prototyped and delivered and the associated ownership of such foreground.

- The RECONASS Monitoring System (RECONASS Consortium); which includes
    - a network of sensors (acceleration (GS), temperature and strain (ARU),
    - local positioning system (LPS) tags (TUD),
    - datahubs (for collecting the sensors and tag data) (GS) and
    - a communication gateway module (to gather all the data in the appropriate format ready to be sent to the PCCDN tool) (ICCS);
    - The Assessment Module (the PCCDN tool (RISA) along with the structural (DBA), economic loss and needs assessment modules (ITC)); and
    - The UAV system and relevant assessment modules (ITC).

**Clustering and Liaison Activities:**

In relation to the collaboration and liaisons with other projects, initiatives and organisations the following apply. Work with collaborated projects involved transfer of knowledge and common participation to events; work with relevant initiatives concerned promotion of the RECONASS results for pushing policy, legislation and standardisation changes in regards to adoption of the RECONASS monitoring system and its knowledge outputs; work with organisations involved integration of RECONASS with external systems and exchange of knowledge in the building monitoring and crisis management domains.

**Projects:**

DESTRIERO – A DEcision Support Tool for Reconstruction and recovery and for the IntEroperability of international Relief units in case Of complex crises situations, including CBRN contamination risks (http://www.destriero-fp7.eu/;) ; PreEMPTIVE - Preventive Methodology and Tools to Protect Utilities, http://preemptive.eu/) ; ICARUS – Unmanned Search and Rescue, http://www.fp7-icarus.eu/) ; EUCONCIP – European Cooperation Network on Critical Infrastructure Protection, https://www.euconcip.org/index.php) ; STREST – Harmonised approach to stress tests for critical infrastructure against natural hazards, http://www.strest-eu.org/opencms/opencms/) ; REAKT - Strategies and tools for Real Time EArthquake RisK ReducTion (www.reaktproject.eu) ; AISIS - Automated generation of information and protection of critical infrastructures in the event of a disaster (http://www.aisis-innovation.org/); NERA - Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation (http://www.nera-eu.org); VERCE - Virtual Earthquake and seismology Research Community in Europe e-science environment (http://www.verce.eu/) RAPIDMAP - Resilience Against Disaster with Remote Sensing and GIS (http://rapidmap.fbk.eu/)

**National and European Initiatives:**

GEM – Global Earthquake Model (http://www.globalquakemodel.org/gem/); United Nations, UNISDR - The United Nations Office for Disaster Risk Reduction (http://www.unisdr.org/). ; BERISUAS - Better response and improved safety through unmanned aircraft systems

**Pilot Testing Liaisons:**

On the occasion of the pilot test (in Älvdalen on 25th and 31st of August) significant efforts have been made by the consortium to establish liaisons with external parties on the exploitation of the event and testing process.

Within the liaisons context additional instrumentation means have been deployed: a) A laser scanning/total GPS base station system has been set in place so as to measure the building's reactions to blast with mm accuracy; providing an additional evaluation metric for the RECONASS system. b) High-frequency accelerometers and pressure gauges have been also installed so as to measure the pressure wave and the blast impact subjected to the building. The former has been brought by THW (RECONASS partner) and the latter instrumentation means has been offered by the Norwegian Defence Estate Agency (NDEA) that showed special interest on clustering with RECONASS and exchanging knowledge on building monitoring tools as well as the process to be followed for "building back better" resilient structures that are capable of withstanding high-stress events. NDEA and RECONASS consortium have signed a non-disclosure agreement on exchanging pilot findings and have established a mutually beneficial collaboration that may advance commercialisation aspects of the RECONASS system. Moreover, RECONASS consortium and Applied Science International (ASI) have proceeded to a collaboration agreement to extend PCCDN tool's functionalities. ASI have produced modelling of the pilot structure and created a simulation layout of the damage results to be incurred due to the foreseen explosions in an effort to upgrade the PCCDN tool's services and embed training capabilities. As such the PCCDN tool is not only considered a disaster management platform (tailored to buildings' monitoring) but also as a training tool for first responders to plan their interventions in damaged buildings.

Post-pilot the RECONASS Consortium have been approached by JRC on creating new and meaningful collaboration opportunities. JRC showed particular interest on the RECONASS monitoring tool (structure's instrumentation and subsequent assessments originating from algorithms and UAV images) and they have proposed integration with the FRT (Field Reporting Tool) the latter developed by JRC (see ""JRC+IFB Field Reporting Tool applied to Middle Italy earthquake event" presentation in http://reconass.eu/index.php/media-centre/news/11-events/50-final-workshop.

**Standardisation and Patenting:**

- RECONASS project participated via presentation at the CEN-CENELEC JW8 conference on privacy by design in January 2016 (accepted to participate regularly as project liaison).
- The RECONASS Consortium have targeted the reconstruction field and in particular links with UNISDR towards contributing to one of its fundamental directions on "building back better". In more detail, RECONASS monitoring system's set of data (sensorial and assessments) can be of great importance on updating (re-visiting) building codes and on creating new ones for monitoring buildings. Consequently, initial contacts have been performed with UNISDR representative Prof. Virginia Murray, who acts as Vice-chair of UNISDR Scientific and Technical Advisory Group (STAG) so as for RECONASS to pass on relevant knowledge and in turn positively influence future developments with respect to the regulations of building codes.
- 3 patent ideas submitted by TUD on Local Positioning System (currently they are under review by patent lawyer);
    - method of integrating our LPS technology with standard Wi-Fi access points to make use of the already present infrastructure in many buildings;

- enhanced spectral estimation method which we use to make processing of positioning data faster
- an alternative fast method for estimating ranging and positioning data using our hardware

- We investigated the possibility to use a German ministry of science research validation programme (called 'VIP+') to move the LPS towards a product; the validation programme requires a short proposal of around 30 pages which we are currently working on (link in German: https://www.bmbf.de/de/vip-technologische-und-gesellschaftliche-innovationspotenziale-erschliessen-563.html)

**Exploitation Plan Route for the overall RECONASS Monitoring System:**

The main exploitation result from the project is the overall RECONASS system as a fully customisable integrated system based on the specific needs of the end user customer i.e. the building owner / operator. The implementation to the pilot scale demonstration of the integrated system prototype within a near scale operational environment, with all its functionality tested, led Technology Readiness Level 7 (TRL7).

The following business analyses have been performed toward the commercialisation path of the system:

- Business Model Canvas for Overall RECONASS System
- Vertical markets identification, a solution on its own to owners and operators of significant valued building structure
- Horizontal markets identification, LPS Tags on tracking applications, Communication Gateway Module on Building Management Systems, Renewable Energy and Smart Meter Monitoring, Remote Home Automation Systems, UAV system on border control, law enforcement, wildlife research, agriculture, mapping and natural resource extraction
- RECONASS Face-to-face exploitation targeted interviews; Interamerican (Insurance Company), Skysense (UAV docking station supplier), Hellenic Ministry of Defence - HMoD (Civil Protection & Defence), Zurich Insurance (Insurance Company), British Damage Management Association (Network of Practitioners)
- Production of product brochure, documentation of the system and web demo for potential customers
- Segmentation of RECONASS users, we identified that building owners and managers were key market actors and that we should focus on these in subsequent activities. Moreover, Civil protection organisations and insurance companies can be directly benefitted from an operational RECONASS system thus are considered of pivotal audience during market penetration efforts. From an exploitation perspective and concerning the civil protection agencies that are to act as system's operators, it has been identified that they may not be in position solely to proceed to system's purchase. However, the vast majority of civil protection stakeholders recommended that central authorities (at a Minister level) need to be approached for exploiting commercially the system's merits and functionalities and provided that a certification process has been performed.
- Market search, to help gauge the interest in the RECONASS (SHOX) technology we conducted an online survey. This survey was targeted at the building owners and managers who we had previously identified as key to the adoption of the technology.
- Competitor analysis, of the structural monitoring market place revealed, the nearest competitor in terms of features is a product called Reflex.
- Creation of a product name or brand, 'SHOX – Structural Health Monitoring in a box'.
- Product website, http://www.shoxsolutions.com/
- Product video, https://www.youtube.com/watch?v=78UjdoktUWA&feature=youtu.be
- Cost benefit analysis, constructed to be used within the consortium to explore how different sized organisations, different sized buildings in different locations could benefit from RECONASS (SHOX).
- Sales forecast analysis, to promote setting up a joint venture company to act as a vehicle to aid the exploitation of the RECONASS technology.
- Exploitation Plan Gantt Chart towards commercialisation

### 4.1.5 Address of project public website and relevant contact details

As projected from the various RECONASS dissemination activities, a public website and other social groups have been created since the on-line presence of a project or initiative are nowadays considered to be a powerful tool towards diffusion of knowledge to all possible directions and audiences, permits interaction with individuals, groups, initiatives and projects that share similar interests and increases significantly the overall impact.

- Project Website: http://reconass.eu/
- Linked In Tool: RECONASS
- Twitter Tool: RECONASS
- SHOX – "Structural Health Monitoring in A Box": https://www.shoxsolutions.com/

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