ELASSTIC CONTRIBUTES TO THE RESILIENCE OF INFRASTRUCTURES

AUTHOR(S): ANS VAN DOORMAAL (TNO) AND MARJOLEIN VAN DER JAGT (TNO)

Paper for
Critical Infrastructure Protection and Resilience Europe

4th and 5th of March 2015, The Hague

Abstract

The growing world population, the ongoing urbanization, the ever increasing size, height and complexity of large scale built infrastructures lead to higher risks with respect to natural and manmade threats. In case of a real incident, the number of casualties and injured people and the amount of damage is larger, unless the resilience of the urban complexes and infrastructure is increased. Resilience (or its hyponym elasticity) is the ability to endure an incident with limited or no consequences and the ability to recover after the incident.

Therefore, the ELASSTIC-project aims at improving the security and resilience of large scale complex infrastructures in order to safeguard the infrastructure and its occupants during its entire life-cycle. The ELASSTIC-project is a research project, co-funded by the 7th Framework Program of the European Commission. Besides the analogue with resilience, ELASSTIC is also the acronym for Enhanced Large scale Architecture with Safety and Security Technologies and special Information Capabilities.

In the project, different types of stakeholders, such as architects, engineers, and scientists, work together to develop concepts and tools for including safety, security and resilience into the design of a multifunctional resilient large scale urban complex. Considering resilience at the planning and early design phase is considered the most efficient and successful approach. The features and the applicability of the concepts and tools will be evaluated and demonstrated through a showcase design, the so-called ELASSTIC complex.

The paper will give an overview of the project, including the ELASSTIC complex and the key features that contribute to the resilience.

Consortium: TNO, Arcadis, Fraunhofer Gesellschaft, Schüβler Plan, Siemens AG, NXNW Architects, JA Architects, Institutivo Consultivo Para el Desarrolo, Uniresearch BV.

Contents

1 Introduction / background

Today, the majority of the world's population lives in urban areas and according to the United Nations, by 2050 that number is expected to rise up to 2/3th of the global population [1]. The growing world population, the ongoing urbanization, the ever increasing size, height and complexity of large scale built infrastructures lead to higher risks with respect to natural and manmade threats. In case of a real incident, the number of casualties and injured people and the amount of damage is increased.

The most striking incident in the past decades was the terroristic attack on the twin towers in New York on September 11th 2001 [2]. The impact of the passenger jets destroyed large parts of the structural elements, but not enough to cause a direct collapse. The following intense fire led to gradual loss of strength and stiffness of the steel support system, resulting in a catastrophic failure of the entire structure with a large number of casualties, including firemen and first responders who went into the building to rescue occupants. The damage was not limited to the two towers, but also extended to the surrounding infrastructure, such as adjacent buildings and the metro system underneath, due to the interconnectedness.

Another striking incident is the earthquake and tsunami that hit the North East coast of Japan in March 2011. Entire villages at the coast were destroyed. Around 25000 inhabitants were killed or got missing [3]. A large part of Japan was cut off for a long time of utilities such as running water and electricity. And last but not least, the tsunami triggered the Fukushima Daiichi nuclear disaster.

These two examples show how massive and disruptive natural and manmade threats can be. The chaos however is more due to the failure of the infrastructure than due to the incident itself, as people and first responders lack the possibility and means to act efficiently and safely.

Evidently, there is a need for improvement of the security and resilience of large scale complex infrastructures in order to safeguard the infrastructure and its occupants during its entire life-cycle, including regular operational processes as well as exceptional crisis situations. It is the intention of the ELASSTIC project to contribute to this need by developing a comprehensive approach for the design of safe, secure and resilient large scale built infrastructure.

2 The ELASSTIC Concept

The ELASSTIC concept consists of the following principles and definitions:

1. Resilience aims at increasing the general resistance and regeneration capability of the structure and the technical systems, such that the resilient complex is capable of “bouncing back to ‘normal’ status” (note the synonym elastic) in case of an incident.
2. Safety, security and resilience are already to be considered in the planning and design phase. This gives the best opportunities to include resilience in the design in a cost effective way.
3. Information is a key value for both the planning and design phase as well as the operating phase. Information needs to be shared, saved, maintained and updated at all times.
4. Choices or decisions are supported by information and analysis and are borne by the entire team of stakeholders. The consequences and the impact of the choices are known.

Architects, consulting engineers and clients should work closely together when designing a building with a high risk profile. They set to work diligently with drawings and calculations, making sure to include security measures in their plans. They are generally advised by a security consultancy in this regard. The security measures consist of structural measures as well as of operational measures.

For this process, the ELASSTIC team develops a comprehensive design approach and supporting tools, such as:

- Extended BIM-technology, i.e. Building Information Modelling program including a set of tools to enable architects, structural engineers and building services engineers to assess the safety, security and resilience of designs;
- Smart and reinforced building elements;
- Coupling and integration of BIM and BMS (Building Management System);
- Real time information on the safety, security and resilience of infrastructure for a smart evacuation system.

The design process will be tested and validated by making a design of a multi-functional, resilient large scale urban complex, the ELASSTIC complex. It is a showcase to demonstrate the features and potential of the ELASSTIC-concept (see Figure 1), i.e. Enhanced Large scale Architecture with Safety and Security Technologies and special Information Capabilities.

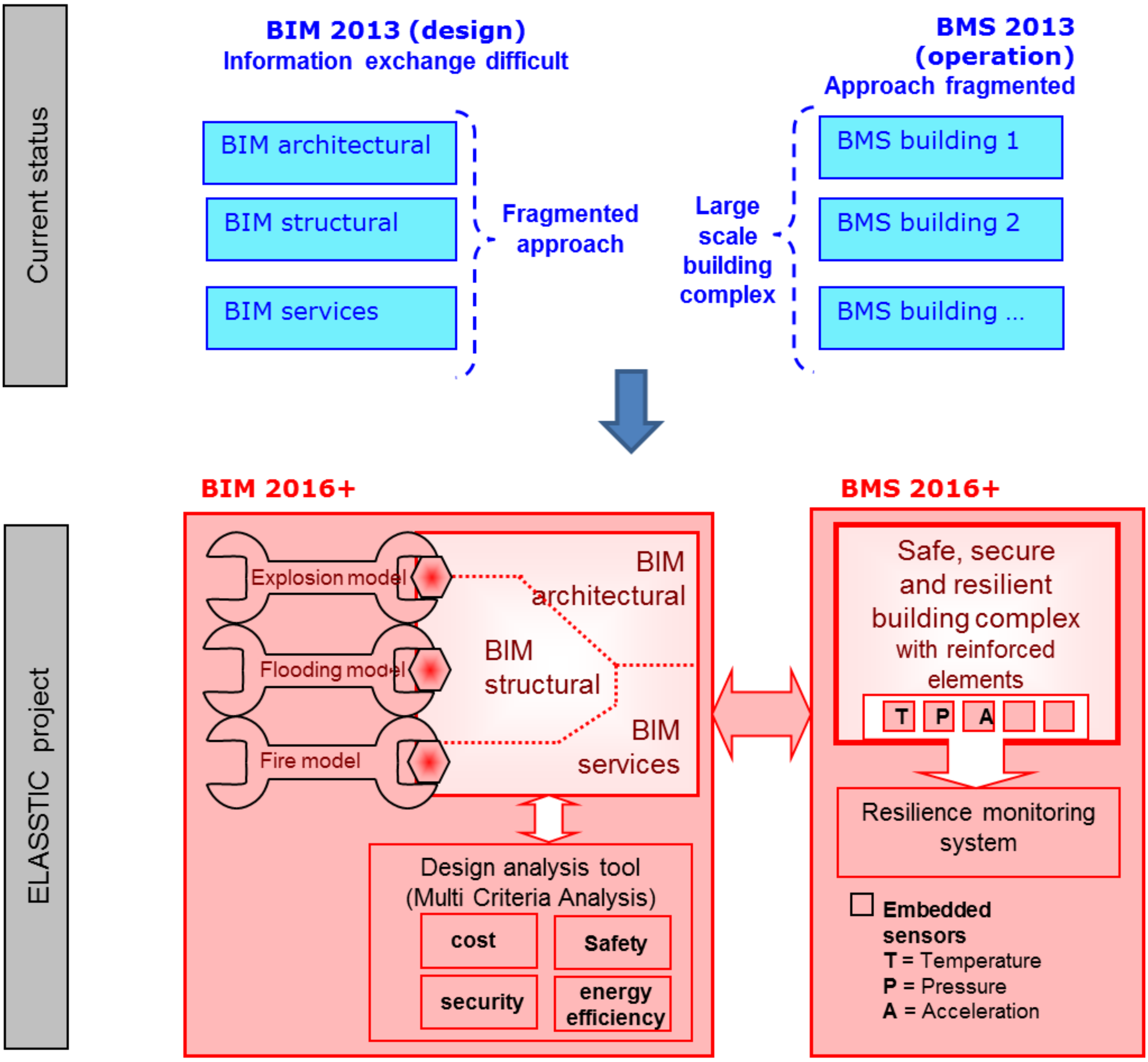

Figure 1 The ELASSTIC concept, its key features and the major innovations.

3 Tools and technologies

This chapter gives an overview of the tools and approaches explored and developed in the ELASSTIC-project.

3.1 Extended BIM Technology

BIM is short for Building Information Modelling. It is a concept where a building is modelled in a computer with intelligent objects (instead of 2D lines). The digital representation of a facility in BIM covers more than just geometry. It also covers e.g. spatial relationships, light analysis, geographic information, and quantities and properties of building components. The use of BIM is spreading and increasing.

The increased use of information technology has brought along the possibility of instant exchange of information as well as the possibility of building 3 dimensional models used for visualizations. Combining these elements, we can see the first signs of an integrated design process where architects, structural and services engineers work with an electronic exchange of drawings. Issues and improvements can be judged and improved upon in a compact timeframe. The usage of 3D models allows a perspective view, allowing clients and users to have an image of the final result as well as allowing engineers to check and improve immediately.

The BIM concept however envisages more. The BIM is a shared knowledge resource forming a reliable basis for decisions, not just for the design process but for the complete life of a facility or building – from the early concept to demolition. With BIM, a computer can automatically perform analyses and simulation runs on the computer model of the building. Dynamic information about the building, such as sensor measurements and control signals from the building systems, can also be incorporated within BIM to support analysis of building operation and maintenance.

It are these features, decision support, (semi-)automatic calculations and dynamic building information during the entire lifetime, that are the focus in the ELASSTIC project in relation to resilience, safety and security. It is the objective to deliver a benchmark of extended features of BIM by coupling with building management software (Siemens), with decision tools (TNO) and hazard consequence models (TNO).

3.2 Building Management System (BMS)

The BMS is considered to be the heart of the building control, at all instances, but particularly in case of a crisis. Future (in 10 years or more) features of BMS are:

- The BMS will record all sensor data and hazard data in a BMS data base connected to BIM.
- The Building management system (BMS) will analyze these data and send a signal which floors, part of floors or rooms of the building (based on building sensor data) and how many persons are affected by the different types of hazards.
- The BMS coordinates and guides the evacuation via signals.
- Moreover, the BMS signal can be used to trigger the building control systems, e.g. HVAC systems or shut down of oil/ gas supply or elevators. In addition, the signal can be used to close fire doors or separate fire compartments.

For example the ‘fire’ scenario. A fire starts at a critical place in a building; one main exit route is completely blocked by the fire: for the evacuation of all persons, a dynamic and individual rerouting is requested. This is controlled by the BMS, based on real time interactive simulation of the evacuation and the expansion of the fire. A database with representative simulation data is a backup approach for this real time protocol. High temperature sensors embedded in ceilings will be used to assess the accessibility of the above floors for safe evacuation routing.

The role of BMS relies on the availability of real-time and accurate data of the status quo of the building. Special sensors are needed to measure this data. The availability and development of sensors and their performance is therefore another research topic within the ELASSTIC project, besides the development of evacuation modelling and the coupling between BIM and BMS.

3.2.1 Evacuation modelling

In cases of emergency evacuation, people in the critical areas move immediately away from the threat or actual occurrence of a hazard. Effective emergency evacuation of the population in case of various hazards is a cornerstone to save people’s lives. Evacuations range from small scales of a building all the way to large scale of evacuation of a district.

Pedestrian stream simulations are nowadays considered an appropriate approach to evaluate and mitigate risks in critical situations. Buildings can be planned with a focus on safety, making use of virtual pedestrian stream simulation experience. With the help of a simulation tool, a trained user can run through multiple what-if scenarios to gain experience for situations where it is impossible to gather empirical data.

However, the modern pedestrian stream models usually do not consider the effects of hazards. They are usually limited to the modelling of evacuation situations related to the occurrence of critical crowd densities or at best the behaviour of people in cases of building fire.

ELASSTIC-partner SIEMENS analyses four types of hazards and their effects on evacuation possibilities and strategies. Based on this information an improved pedestrian stream model will be developed for people evacuating from buildings in case of earthquakes, high wind loads as present during hurricanes or tornados, explosions / fire and flood disasters, particularly flash floods. The overall objective of the work is to identify and standardize measures, which allow us to maintain the building or urban infrastructure (at least as long as required to ensure safe evacuation of all occupants).

It is evaluated how down-time after disasters in urban and building infrastructures can be minimized through increased resilience or means of fast recovery. A classification scheme is proposed, which allows the prediction of disaster impact (by category) and thus provides basis for recommendations on how to improve resilience sensor-based building management systems (BMS).

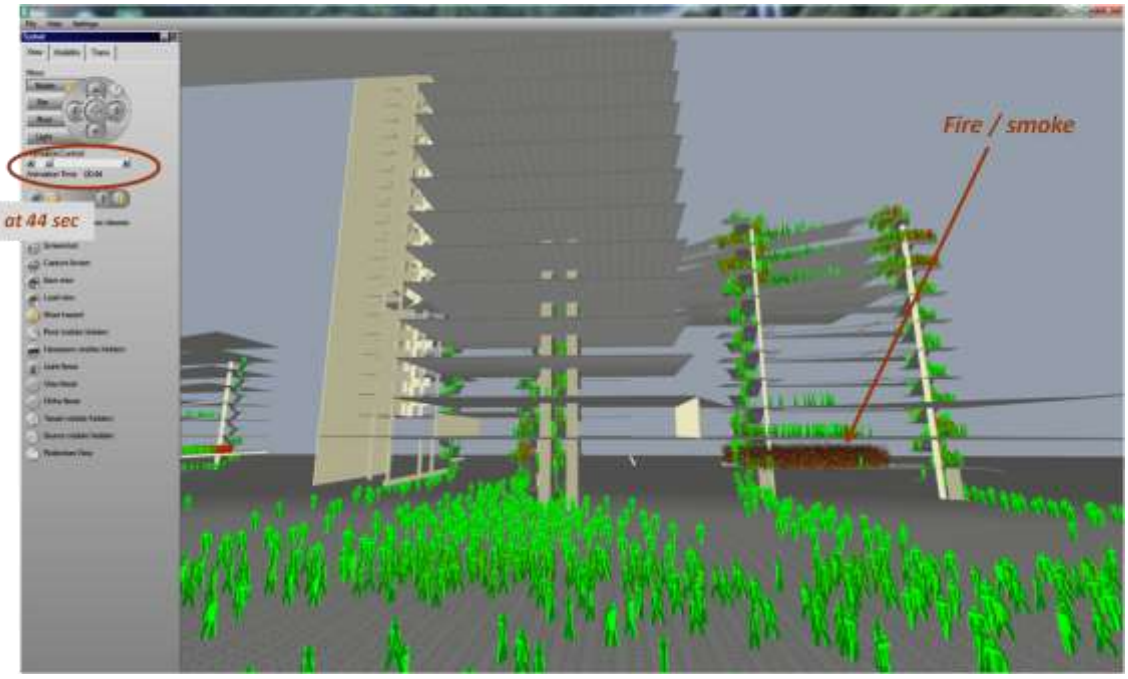

Figure 2 Example of evacuation simulation

3.2.2 Wireless sensor network (WSN)

ELASSTIC-partner EMI (Fraunhofer Gesellschaft) studies the possibilities of wireless sensor networks for the ELASSTIC-concept (see [4] and [5]).

Wireless sensor networks are small low-energy electronic units with transceivers that have limited computational and memory resources. They operate autonomously to accomplish a specific measurement task. Currently, WSN are mostly used for environmental applications such as environmental or disaster monitoring. Depending on the sensor type, in general, they query the physical world with sensing, processing, storage and communication capabilities integrated in a single device. Other current applications include building monitoring, building automation, factory automation, and body area networks. Little has been done so far in the application of WSN for time critical events as is the scope within the ELASSTIC project.

Self-sufficient wireless sensor networks in terms of energy supply are relatively new. The main challenges pose the energy harvesting methodology, the energy management and conversion efficiency, and the wake-up receiver. Key factors to address these challenges are efficient computation algorithms, intelligent routing protocols, intelligent synchronization, and the localization. One crucial criterion for an energy autarchic WSN is the power efficiency. The transmitting and receiving process require most of the electric energy when compared to other processes such as CPU operation and idle or sleep modes.

The functional requirements for the WSN within the ELASSTIC project are chiefly to provide relevant data in the case of a threatening event, such as information on the type of event, its severity and how and where it effects the building. Thus, functional as well as robustness and operational requirements for the sensors and the WSN have been identified.

A schematic overview on the envisaged WSN is depicted in Figure 3. The power supply for the WSN is being designed as an energy harvesting module embedded in floor tiles, which generates electric power using the compression / decompression cycles under pedestrian traffic. The work will also include a study to the integration of the WSN in the structure, and smart elements to protect the sensors and the WSN.

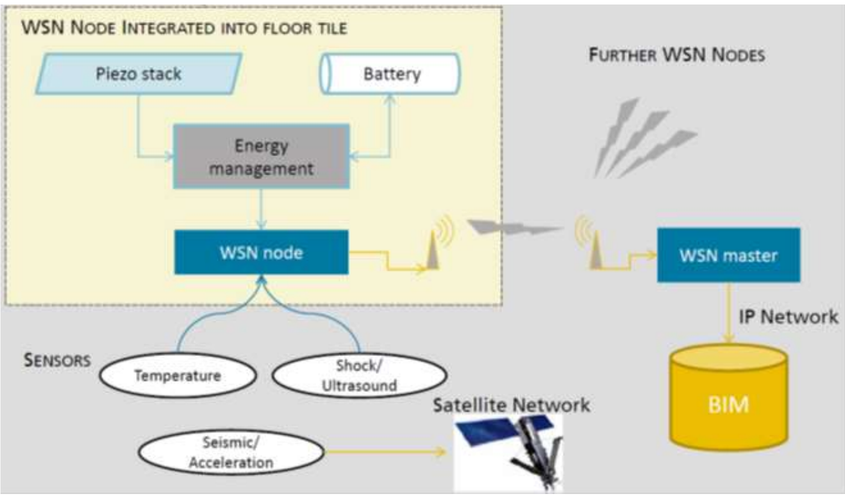

Figure 3 Sensor system overview.

3.2.3 Legal and ethical issues

The building management system comprises the necessity to gather data in favour of the safety of the people. To be able to do this in a legal way, the fundamental rights liable to be affected by protection of data are a need to know. The right to protection of personal data is defined by the European Data Protection Supervisor as “a fundamental right.” It is different from, but closely linked to, the right to respect for private and family life. This distinction is notably made in the EU Charter of Fundamental Rights - which mentions the two rights separately, although next to each other in Articles 7 and 8.

Data are personal data if they relate to an identified or at least identifiable person. Form of appearance of the data could be: Written or spoken communications, images, CCTV footages or sound, electronically recorded and stored information.

Partner INCODE has listed the legal rules ELASSTIC has to take into account when gathering data [6]. These are:

- Data must be processed fairly and lawfully.
- They must be collected for explicit and legitimate purposes and used accordingly.
- Data must be relevant and not excessive in relation to the purpose for which they are processed.
- Data must be accurate and where necessary, kept up to date.
- Data controllers are required to provide reasonable measures for data subjects to rectify, erase or block incorrect data about them.
- Data that identifies individuals must not be kept longer than necessary.
- In principle, all data controllers must notify supervisory authorities when they process data.

3.3 Multi Criteria Analysis (MCA)

The design process of a large scale and multi-functional urban building is complex. It deals with multiple stakeholders who have a wide range of stakes, divergent priorities, different time horizons and different scales of the investments. In such complex, and multi-layered processes, there is a need for a decision making tool that supports the stakeholders in making choices among the different design solutions through assessing the performance of design alternatives based on selected criteria. Thus, the aim of using Multi Criteria Analysis (MCA) in ELASSTIC is to develop a tool to enable quantitative judgment of an integral design, based on a set of design performance criteria defined by the stakeholders. Thanks to the joined efforts, the result is widely supported.

In ELASSTIC the MCA will particularly be used to judge the safety and security features of the design against criteria concerning architectural quality, functionality and environmental impact (See Figure 4). Via the MCA tool, the stakeholders (particularly the designers) can see the immediate impacts of the design changes on the performance of the whole complex with respect to the criteria. Within ELASSTIC, the MCA tool will connect (manually or automatically) to the calculation and simulation models, as it will use the data from the models.

Figure 4 MCA-tool interface, showing the top level criteria .

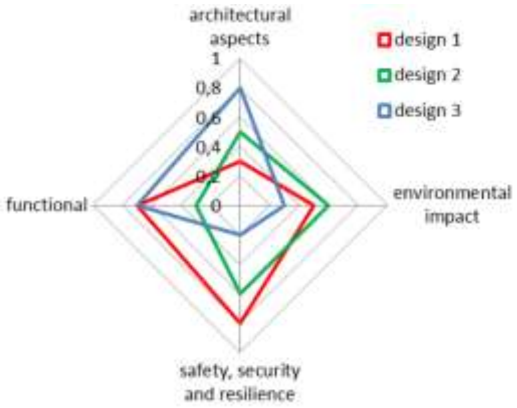

Figure 5 Example of visualisation .

The MCA tool itself is developed by TNO and consists of a user interface and the back-end architecture that explores the connection with the BIM server and the calculation and simulation models. The visualisation of the results can be in different formats, as it will help the stakeholders to compare and make decisions. An example is given in Figure 5. The MCA tool will therefore enable the stakeholders to make explicit choices and provide reasoning behind their chosen alternatives. Due to the reasoning and explicit results, the MCA tool will support the iterative nature of the design and assist the stakeholders to keep track of design changes.

3.4 Relatics

Relatics is a tool used by Arcadis to realize the design matrix. Relatics can be used to manage project information, requirements, stakeholders, verifications, risks, changes, tasks, project objects and design parameters. It gives a method to structure all project information into one database.

System engineering (SE) is used to define the project;

- Objectives – higher holistic level;
- Functional demands - to fulfil objectives;
- Systems/objects - to fulfil the functional needs.

SE helps to define and structure all quantitative and qualitative specifications. Nothing different than a regular program of requirements but SE provides more structure, a clear coupling of objectives to functional needs and system definition and vice versa, a clear coupling of “indirect” actors.

The emphasis within ELASSTIC is put on defining the functions and objects, and the relationships between hazards and objects. The result anticipated is:

- A database is created which reflects the building requirements and design;
- A relationship between objects/functions and hazard scenarios;
- An analogue set up with the BIM model;
- A coupling is created with the BIM model;
- A database used to create Design Matrix for Hazard scenario's.

The ultimate goal is to develop an optimal exchange between Relatics and BIM, so that all information can be shown in the BIM model.

4 ELASSTIC Showcase

Validation (proof of concept) of the approach and developed tools will be done by evaluating the design of a multifunctional, resilient, large scale urban complex, called the ELASSTIC complex. This design is another deliverable of the project. A first quantitative design is available in BIM now, ready for the evaluation.

4.1 Site

The site for the ELASSTIC complex was chosen to be situated in the inner city of The Hague in The Netherlands, directly next to the central station. This location has been chosen as a representative and interesting site. It has to be mentioned however that the site is a showcase and that the complex could be situated anywhere in the world.

4.2 Architectural design

The architectural design was made by the participating architects, JA and NXNW [6]. From a set of nine concepts, the “Ribbon” (see Figure 6) was chosen as the most suitable solution. Being a “Ribbon” concept, the idea was to have a continuous sectional size all along its length. Multiple criteria were taken into account in order to establish the most favourable dimensions given the limitations of the requirements.

Figure 6 The ELASSTIC showcase complex.

The requirements behind the "RIBBON" concept are:

- Functionality: The complex had to fulfil certain programmatic requirements to allow for complex and representative hazard and escape scenarios.
- Safety: The "Ribbon" includes areas which are harder to evacuate than a regular building in times of an evacuation, e.g. long corridors, high towers with long sets of stairs and large public spaces. The aspect of high rise is the result of being able to test the design against the hazard of high wind loads.
- Security: Due to the large span and elevation of the top floors, security issues were deliberately taken into account in the design of the complex.
- Stability: The dimensions of the "ribbon" need to be large enough to allow sufficient structure and central cores to be integrated without interfering with the usable spaces.
- Aesthetics: The idea was to have a continuous sectional size all along its length. Studies were carried out in order to establish the most favourable dimensions given the limitations of the requirements.

The complex includes housing, a theatre, private-sector offices, a hotel, commercial spaces and a public museum with a specific area to receive high security dignitaries.

An example of a typical choice related to the research challenges of the ELASSTIC-project is the theatre. To make the results of the evacuation simulations more interesting, the theatre has been placed at the top of the building, over the main archway, a location which would not likely be considered in real cases due to functional and economic reasons.

Figure 7 Night view impression of the ELASSTIC-complex.

4.3 Structural and services design

The first quantitative design is the reference design for the further analyses. It is the work of Arcadis [9] and includes the design of the structure as well as the preliminary design of relevant services.

The structure is based on the dead load, live load and wind load, according to European and more particularly Dutch laws and regulation. The main part of the structure is concrete, i.e. a combination of concrete cast in place and prefabricated elements The vertical bearing elements are cast in place. The floors are mostly prefabricated. The top structure consists of steel truss structures. The steel structures which are implemented on the upper arches of the ribbons are used in order to make large spans and cantilevers on the top floors possible.

The preliminary design for the MEP discipline (Mechanical, Electrical and Plumbing) is focused on those parts that have an influence on the shape of the architecture and the design of the structures, as well as those which are relevant for the scenario analysis. More specific, location and size of the technical spaces and shafts have been determined in an iterative design process with architect and structural engineers. The level of details is still coarse, which is in line with the required level of detail needed at this point.

5 Future work: Hazard scenarios

The scope of the project is to create a resilient building complex, not only for historical threats and hazards but also for future ones. A thorough risk analysis [9] has been performed to map relevant threat and hazard levels for complexes with typically four functionality sectors (public, public-limited, business, administration). The analyses show that natural disasters are of increasing importance in the planning process of multi-functional building complexes in Europe. The literature points to an increasing trend regarding the number and the magnitude of extreme weather scenarios, like heavy wind or rain, leading to floods. This development is reasoned through the climate change scenarios. A consideration within the planning process is strongly recommended.

Since the middle of the 1990s, an increase of intended incidents as acts of sabotage and terrorism is observed. It is expected that such events will reoccur in the future with an increasing trend. The evaluation of past events shows a higher danger in countries of Eastern Europe in comparison to the entire continent.

In the ELASSTIC project, the following type of hazards are considered:

- Seismic loads (by Schüßler Plan)
- Flooding (by Arcadis and Siemens);
- Fire (by Schüßer Plan and Siemens);
- Impact and explosion scenarios (by TNO, Schüßler Plan and EMI Fraunhofer).

The ELASSTIC complex will be assessed regarding its resilience, safety and security for incidents of the above nature. The focus during the evaluation will be the structural damage as well as the safety of the people in the building complex. A range of simulation models and calculation tools are used for the assessment.

During this assessment, the appropriateness of the different calculation tools for automation will also be determined. If feasible, the most appropriate one will be selected for a benchmark of an automated calculation, controlled by BIM.

Besides the quantitative results regarding the resilience of the ELASSTIC complex, a second result of this work programme, is a blue print for designing resilient building complexes. This blue print will describe the design approach and the lessons learned during the project. This blue print will show how the different tools can be used and how the results can be merged and feed into the MCA-tool, thus leading to the best design decisions and the optimal design.

6 References

[1] United Nations Human Settlements Programme (UN HABITAT) 2008: *State of the World's Cities 2010/2011. Bridging the Urvan Divide*, Earthscan: London.

[2] http://nl.wikipedia.org/wiki/Aanslagen_op_11_september_2001

[3] http://nl.wikipedia.org/wiki/Zeebeving_Sendai_2011

[4] Dr. Frank Schäfer, Georg Schäfer, Clemens Horch, Dr. Malte von Ramin, Oliver Millon, Dr. Davidich, Dr. Klein, Dr. Mayer, *Overview of wireless sensor systems and networks*, ELASSTIC deliverable D3.2, 17 October 2014

[5] Christian Brenneis, Oliver Millon, Dr. Frank Schäfer, *Performance of existing sensor solutions*, ELASSTIC deliverable D3.3, 16 December 2014

[6] Antonio Silva, *European Reference Standards Privacy and Data Protection*, ELASSTIC deliverable D4.1, 17 October 2014.

[7] R.F. Thomas, *Architectural Design ELASSTIC Complex*, ELASSTIC deliverable D2.2, 20 May 2014.

[8] R.F. Thomas, S.F. Surja and R.A. Boukens, *1st Coordinated resilient design of the building*, ELASSTIC deliverable D2.3, 19 December 2014.

[9] O. Millon, T. Rinder, M. von Ramin, *Hazard scenario definition*, ELASSTIC deliverable D1.2, 5 November 2013

7 Acknowledgment

"This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 312632".

http://cordis.europa.eu/fp7/cooperation/home_en.html

http://ec.europa.eu

PROJECT PARTICIPANTS:
TNO – NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK (NL)
ARCADIS NEDERLAND BV (NL)
FRAUNHOFER-INSTITUT EMI (DE)
INSTITUTO CONSULTIVO PARA EL DESARROLLO SL (ES)
JA JOUBERT ARCHITECTURE (NL)
NORTH BY NORTH WEST ARCHITECTES SARL (FR)
SCHÜBLER-PLAN INGENIEURGESELLSCHAFT MBH (DE)
SIEMENS AG (DE)
UNIRESEARCH BV (NL)

Project website
www.elasstic.eu

Disclaimer
The FP7 project has been made possible by a financial contribution by the European Commission under Framework Programme 7. The Publication as provided reflects only the author's view.

Every effort has been made to ensure complete and accurate information concerning this document. However, the author(s) and members of the consortium cannot be held legally responsible for any mistake in printing or faulty instructions. The authors and consortium members retrieve the right not to be responsible for the topicality, correctness, completeness or quality of the information provided. Liability claims regarding damage caused by the use of any information provided, including any kind of information that is incomplete or incorrect, will therefore be rejected. The information contained on this website is based on author's experience and on information received from the project partners.