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Publishable summary

The overall objective of the ELASSTIC project is to improve the security and resilience of large scale multifunctional building complexes to natural and man-made disasters by providing a methodology and tools which enable to include security and resilience from the early design and planning phase of such projects.

The ELASSTIC concept proposed is based upon the following key features:

1. A comprehensive approach for designing safe, secure and resilient large scale built infrastructures
2. A set of tools to enable architects, structural engineers and building installation engineers to assess the safety, security and resilience of designs and to optimize the integral design
3. Coupling and integration of these tools into State of the Art Building Information Modelling (BIM) technology resulting in Extended BIM technology (BIM+)
4. Smart and reinforced building elements, to measure the actual building condition combined with an increased bearing capacity and resistance
5. Coupling and integration of BIM and BMS (Building Management System)
6. Real time information on the safety, security and resilience of infrastructure

Validation (Proof of Concept) of the approach and developed tools has been done by evaluating the design of a multifunctional, resilient, large scale urban complex (anno 2020), called the ELASSTIC complex. This fictitious complex has been designed in the project. This large multifunctional complex combines housing, shopping centre, business centre and entertainment centre. In this design, safety and security are integrated to make the complex resilient to natural and manmade threats.

Resilience is about being able to bounce back to normal, thanks to robustness, flexibility and assurance of fast and efficient evacuation in case of a disaster. Thus lives can be saved and business continuity is retained. For a crowded complex comprising a large number of people, the design of a smart evacuation system and consideration of safety and security aspects should be included at the start of the complex design. Taking evacuation and safety features into account in the design phase will increase safety and is less expensive compared to safety features integrated after the complex is build or at the final design stage.

1 Project context and main objectives

1.1 Context

A fundamental function of a building is the protection of people against all kinds of effects. This is quite normal when it concerns phenomena that happen frequently, like rain or noise. It becomes more difficult when the phenomena are extreme and have a low probability of occurrence. Think of large natural hazards such as earthquake, flooding and extreme wind, or of manmade incidents, like explosions and impact. Protection against such hazards is special and not so often considered. But in case of an incident, the consequences are huge. That is the reason why one cannot neglect them.

Both natural hazards and manmade incidents are becoming more and more important. The worldwide climate change appears to go along with an increasing number and magnitude of extreme weather scenarios, like heavy wind and rain, leading to floods. Regarding man made incidents, particularly terrorism is showing an increase since the middle of the 1990s, and there is no sign yet that this will decrease soon.

To design against these threats may seem hopeless. They are extreme and devastating. And how can one predict what exactly will happen? Experts (of the ELASSTIC consortium) however do know that it is very worthwhile to evaluate a design against a range of hazards. The benefit is not often to make the design completely resistant, but to remove very large vulnerabilities and weaknesses from a design and to limit the consequences of an incident. The assessment also contributes to the preparedness for a possible incident.

Ideally, safety, security and resilience are already included at the planning and design phase of large multifunctional complex infrastructures. In ELASSTIC, the approach and building blocks for this purpose are developed and integrated in close cooperation with key players in planning, design, building and management of large building complexes. A 3D blueprint (design) of a large multifunctional building complex is made. The purpose thereof is to evaluate the feasibility and suitability of the developed design methodology and tools for future designs of safe, secure and resilient building complexes (Proof of Concept).

The proposed CONCEPT of the ELASSTIC project is presented in Figure 1, in which the key features and innovations of this concept are given. These are also the main objectives of the ELASSTIC-project.

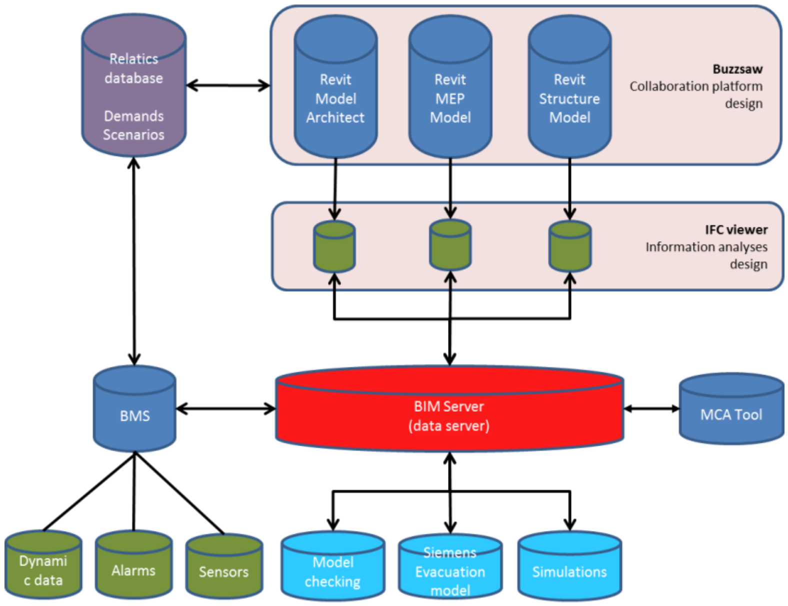

Figure 1 Concept of the ELASSTIC project

1.2 Main objectives

1.2.1 Comprehensive approach for designing safe, secure and resilient large scale built infrastructures

The development of a comprehensive approach should deliver standardized design procedures and protocols for comprehensive security concepts. This holistic approach is based on the following sub-objectives:

- An evaluation of the state of the art in design processes.
- Insight in relevant design aspects/solutions to be taken into account in the design process related to the different hazard scenarios and/or disasters.
- Hazard assessment and tools for hazard assessments.
- An MCA decision methodology that enables the quantitative judgement of a design.
- An MCA decision support tool that guides and registers the decision process.
- Illustration of the evaluation concepts by judging the ELASSTIC-complex.
- Proof of concept for the blue print of the ELASSTIC holistic design process.

1.2.2 Extended BIM technology (BIM+)

Extended BIM technology (BIM+) means extending the BIM technology such that it facilitates the integral design process of architects, structural engineers and installation planners. The extended BIM has to ensure uniform data exchange and storage, process recording and user interfaces for engineering tools and other data systems. Specific ELASSTIC goals with relation to this objective are:

- Gathering experience about collaboration and data exchange through a BIM-server.
- Development of new IFC Delivery mechanisms for the communication process.

- Creation of technical interfaces between BIM server database and simulation tools.
- Information and data exchange between BIM and BMS.

1.2.3 Smart and reinforced structural elements for a resilience monitoring system

The function of smart and reinforced elements in buildings related to safety, security and resilience is twofold, namely

1) An increased resistance against and absorption of high loading energies,
2) Monitoring, detection and identification of an incident.

One of the tasks in ELASSTIC was therefore the development of a multifunctional protecting and sensing structural building elements with improved resistance due to high energy absorption capacity. The approach consisted of the following sub tasks:

- Review of existing wireless sensor platforms, and safety and security systems in building construction
- Performing analysis of existing sensor solutions
- Design of multifunctional sensor-integrated elements
- Experimental studies to determine overall system functionality of complete element

1.2.4 Smart evacuation system with real time information on the safety, security and resilience of infrastructure

A smart system that can provide essential information on the building status real time to the first responders and the people inside can contribute greatly to the safety of people within the building infrastructure. It is the objective of ELASSTIC to bring such a smart system closer to reality through the following sub-objectives:

- Understanding of/database on the impact of hazards on people, assets, systems in a building and structure of a building.
- Specification and realisation of a virtual Building Management System (vBMS) with evacuation modelling.
- Evacuation evaluation tool that facilitates prediction of disaster impact (by category) and thus provides basis for recommendations how to improve resilience of a sensor-based Building Management System
- Evaluation how down-time in urban and building infrastructure can be minimized.
- Software demonstrator of smart real time information from sensor into BMS, actualization of the building state due to hazard information, activating the evacuation analysis for the recent building status
- Overview of ethical and legal aspects related to data collection.

1.2.5 Multifunctional resilient large scale urban complex: the ELASSTIC complex

A multifunctional complex has been designed during the project in order to validate and test the developed approach and the tools. The following steps/objectives have been achieved:

- Definition of a benchmark complex

- Definition of future requirements for the secure and safe building complex
- Definition of relevant hazards.
- A preliminary design of a large scale building complex consisting of architectural design, structural design and design of building service.
- A final design (architectural, structural and building services) as a prototype that demonstrates how safety and security can be improved if all planners regard safety and security as an integral design aim.
- 3D model of the final safe, secure and resilient building complex.

1.2.6 Recommendations for a regulatory framework

Based on the project results, recommendations have been defined how to include resilient and safety based design methods and tools in the design process.

2 The main Scientific and technological results and foreground generated

2.1 Comprehensive approach for designing safe, secure and resilient large scale built infrastructures

2.1.1 Design approach

Including safety, security and resilience in the design of a multi-functional urban complex is a challenge and requires a lot of decisions. Such an urban complex needs to provide a secure and safe space for its occupants and minimize its vulnerability against natural and man-made hazards. From the early design process on already, it is important to make reliable choices to accomplish a safe, secure and resilient building with both desired architectural quality and functional fulfillments.

For this decision making process, TNO with the support of the ELASSTIC-team has developed a holistic design process based on a Multi Criteria Analysis (MCA) approach, consisting of the following special features:

- A design checklist has been generated and implemented in Relatics by Arcadis. Relatics is a system engineering program.
- An MCA software tool has been generated that supports both the initial process of defining and identifying the wishes and the priorities of stakeholders, as well as the process of evaluating the design.
- Key Performance Indicators (KPI's) have been defined, that can be used to quantify the performance of a building related to hazards.
- A methodology has been developed to generate the performance scoring for the criteria. Results from engineering calculations can be translated into scores for the more general KPI's.
- Impact of safety, security and resilience measures on other design requirements have been identified. And this is used to identify generic KPIs playing role in any urban complexes.
- The MCA-tool can be linked to BIM, i.e. output of the analysis with the MCA can be registered and visualized in the 3D BIM-model.

For this process to work well, safety and security engineers need to be part of the design team.

The tool and the criteria have been used to evaluate the design of the ELASSTIC complex.

The criteria development (KPI development) has been a focal point within ELASSTIC, in order to generate a list of representative and relevant set of criteria which were generally applicable. In ELASSTIC from the project goal, safety, security and resilience has been the key criterion. The other main criteria were set up based on conflicting needs with the safety, security and resilience criteria. They were Architectural Quality, Environmental Impact and Functionality criteria.

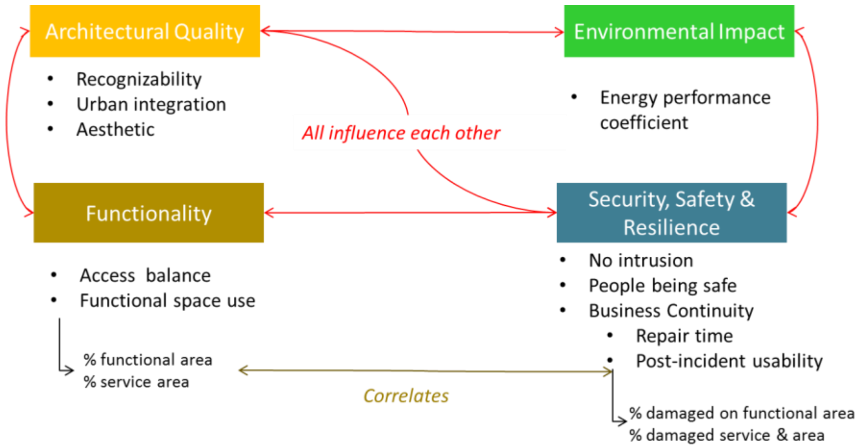

Figure 2 The four criteria defined for assessment of the ELASSTIC designs

The criteria were set in discussion with the partners & advisory group. These criteria were the basis on which the evaluation of the design could be done. Once the four main criteria were identified, they were detailed into sub criteria and these sub criteria have been subdivided as well. The latter two steps have been done parallel to the scenario analysis. It is a parallel process, as during the scenario analyses insights in the problem are gained. Below, the definition of criteria levels is illustrated.

Regarding the assessment of the ELASSTIC designs, the criterion of Architectural Quality was divided into three sub-criteria as follows:

1. Recognisability (whether an urban complex is recognized differently than the ones within surroundings);
2. Urban Integration (whether the building is integrated in the surroundings socially, functionally and physically);
3. Aesthetics (is the positive feeling created by the nature of the building. Proportions and dimensions play a role but it is subjective to a large extent).

Because of the nature of definition of sub-criteria, it is important that the scoring is not based on one opinion, but on multiple opinions. And the input defined for this criterion is therefore an expert judgement method.

The functionality criterion was divided into two sub criteria: accessibility and spatial use. Accessibility was specially considered in parallel with the safety, security and resilience criterion as it can have a negative influence on the access type that was a sub-criterion of the safety, security and resilience criterion, or vice versa. Accessibility here dealt with the access during the opening hours, supply and parking. The choices made here varied from publicly accessible functions to restricted accesses with security checks etc. Regarding the spatial use, the common area factor method was used to determine the ideal/desired spatial ratio based on gross to net area calculations. The input was provided by a query made from the BIM models.

Regarding the environmental impact criterion, the Energy Performance Coefficient (EPC) was used as the criterion. The EPC is an EU-standard requirement in the Building Code to get an environmental permit to build a new utility construction.

The safety, Security and Resilience criterion was the main focus of the ELASSTIC project. This main criterion was divided into three sub-criteria: “No intrusion”, “People being safe” and “Business continuity”. The sub criterion “People being safe” is related to lethality or number of victims in three zones that are to be distinguished: the attacked zone, the non-attacked zone and external. The result for people being safe in the attacked zone is very hard to improve by adjustments to the building, as the people are directly exposed to the hazard phenomena. For the non-attacked zone and external zones, the design itself of the building has a large influence on the amount of victims due to a hazard. For these zones the adjustments (or measures taken to improve the behavior of the design regarding any hazard) can make a big difference in providing people's safety. Business continuity is characterized by repair time and post-incident usability. Repair time refers to the period of time that it will take to repair a damage to (the specific part of) the building. Post-incident usability indicates the possibility to use (the specific part of) the building after the incident. For both, repair time and post-incident usability, the following aspects determine the scoring: 1) structural damage, 2) dirt/rubbish, 3) contamination, and/or 4) service availability (e.g. electricity).

Based on the above-stated criteria (in a tree form), scoring, and input definitions, the MCA tool was built and used. The tool contains different tabs (or working sheets) for different parts of the assessment. Figure 3 presents the so-called criteria tab. It is the tab where the criteria are entered into the MCA tool. The figure also shows instructions for use. Other tabs are the scenario tab for defining and weighing the scenarios, and the solution tab for implementing results from the hazard assessment, the comparison to compare different design alternatives (see Figure 4).

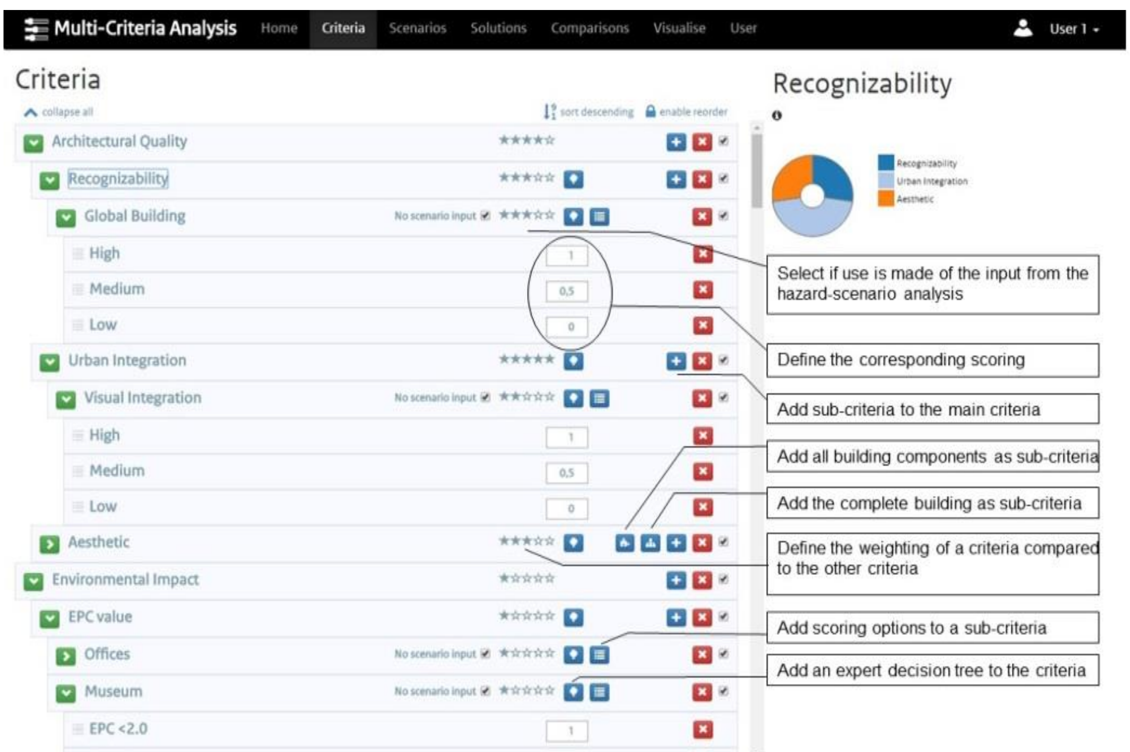

Figure 3 In the Criteria Tab the criteria and the scoring categories were entered based on the reasoning above

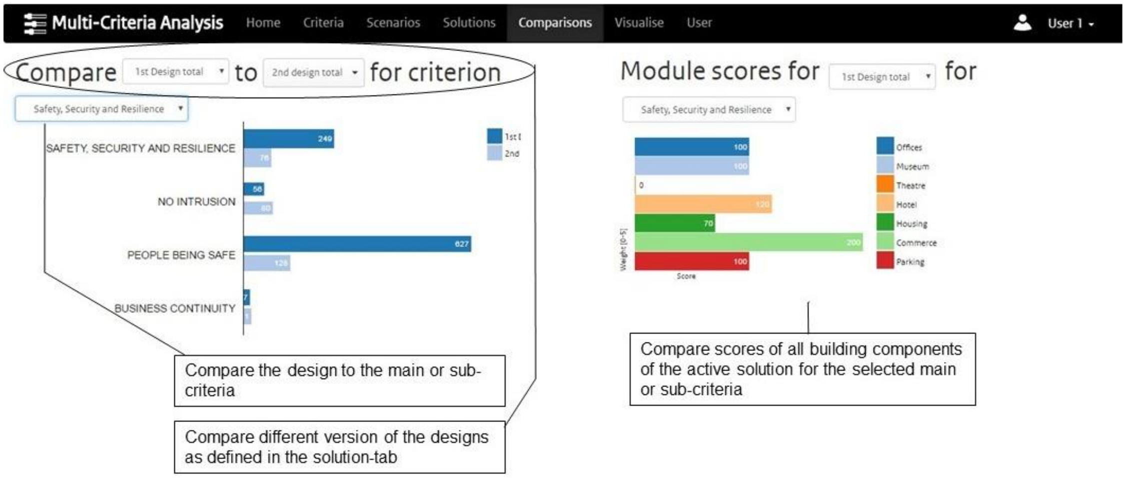

Figure 4   The Comparison Tab was used to make comparison between two ELASSTIC designs

In the different tabs, the results are visualized in bar charts. Another achievement of the project is the possibility to map the results on the BIM geometry, after finishing the MCA assessment. This is done in the visualization tab. Figure 5 shows the final visualization for the ELASSTIC building complex. The visualization was made per function and was done through a connection to the simplified BIM geometry of the ELASSTIC design.

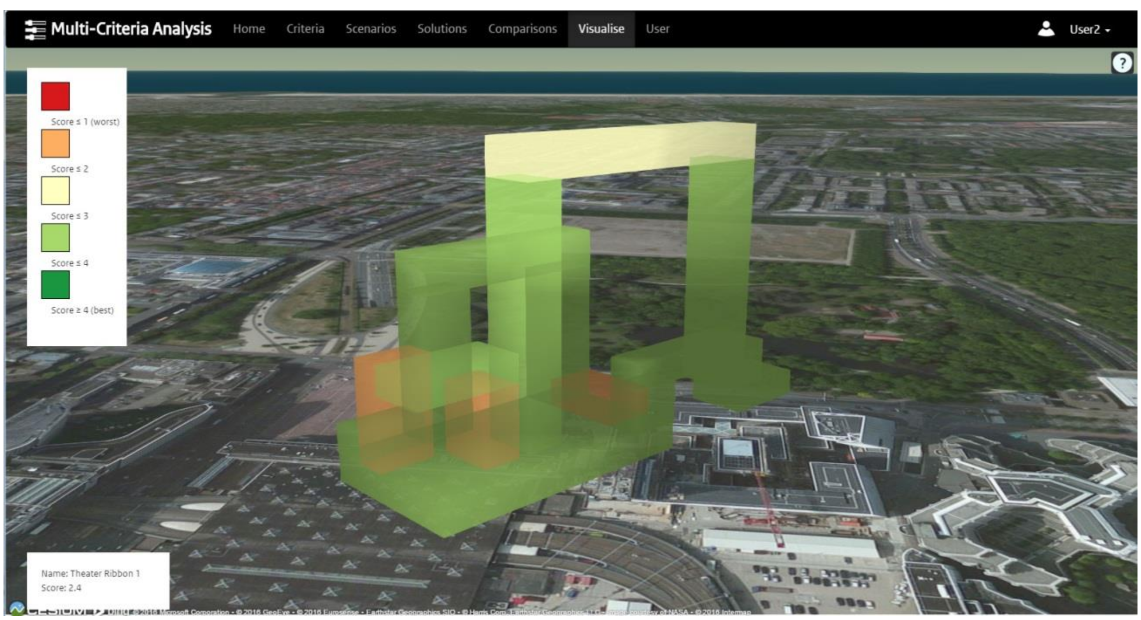

Figure 5   Visualization of the building, showing the score per building component

2.1.2 Hazard assessment

Hazard assessments for the ELASSTIC-complex have been carried out to evaluate the design. The results of the assessments have been used as input in the MCA-evaluation. Flooding, extreme wind, earthquake, plane impact, explosion and a biochemical threat are the hazards that have been considered. Due to climate change and due to the political situation in the world, these hazards have an increasing trend in occurrence. Also the urbanization trend of more people living in urban areas is an additional reason for considering the hazards. Due to urbanization, the world is more vulnerable for extreme events.

2.1.2.1 Flooding

The flooding scenario evaluated by Arcadis, was a dike break at the coast of The Hague. Such a dike break can lead to water levels of 1 to 1.5 m in a substantial part of The Hague within 24 hours, including the center where the ELASSTIC building complex was assumed to be situated. A scenario like this has mainly impact on the business continuity, not so much on the safety of the people as these can evacuate in time.

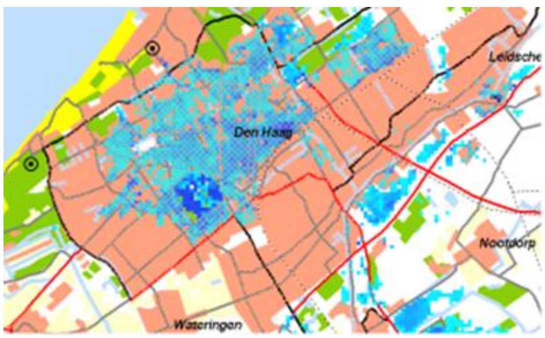

Figure 6 Flooding of The Hague

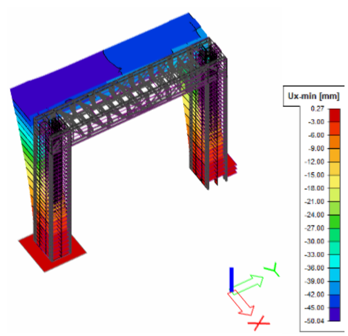

Figure 7 Deflections due to wind load

2.1.2.2 Extreme wind

Normal wind conditions are based on the prescribed wind load within the Eurocode. It concerns a reference period of 50 years. The extreme condition, considered in the ELASSTIC project, is the wind load with a reference period of 100 years. Although this load is higher than the design load (i.e. normal wind condition) of the ELASSTIC building complex, analyses by Arcadis showed that displacements and stresses do not increase significantly. The margin of safety in the design is more than enough to cope with the higher load.

2.1.2.3 Earthquake

Ribbon 1 of the ELASSTIC complex building was analysed for an earthquake scenario by Schüβler Plan. The location of the building is The Hague. In general, in The Hague no design against earthquake is necessary. Nevertheless, it is the general objective of the research project to have a blue print which is valid for different places in Europe. Therefore, an earthquake scenario with a soil acceleration of 3 m/s² was considered, which reflects earthquake scenarios in Mediterranean countries, like Italy.

The objective of this investigation was to verify the design of Ribbon 1 against earthquake. In most cases the highest loading during an earthquake occurs in the ground floor. Therefore, it is important for a verification to check the required amount of reinforcement in the walls of the ground floor and to proof that the theoretically required amount of reinforcement can be built into the walls of the ground floor.

The effects of the earthquake itself and the other loads which occur during an earthquake were taken in consideration and the required reinforcement was calculated. The maximum values of the required reinforcement are approximately 25 cm²/m. This amount of reinforcement is reasonable for a wall with a thickness of 30 cm and can be built into a wall of this size. Therefore, the first design of Ribbon 1 is verified for earthquake scenarios.

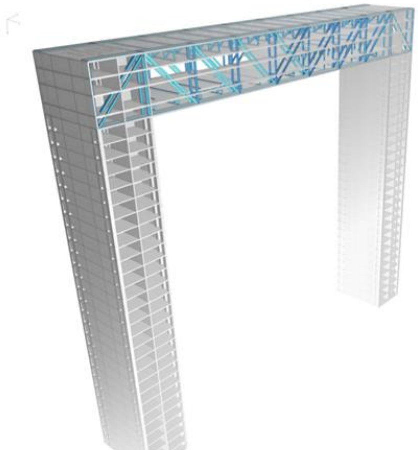

Figure 8 3D model of Ribbon 1 used for the earthquake analysis

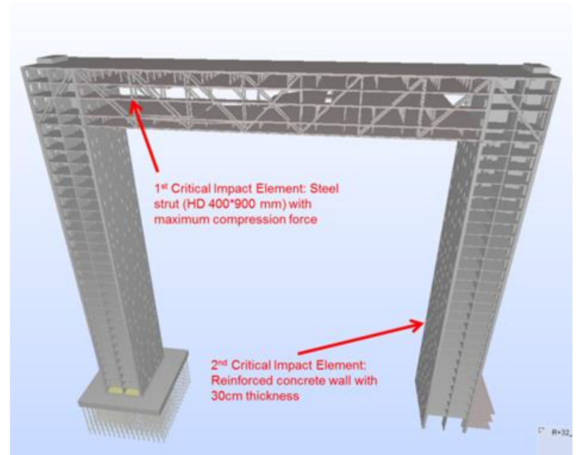

Figure 9 Sketch of considered plane impact scenarios

2.1.2.4 Plane impact

The Ribbon 1 of the ELASSTIC building complex was analysed by Schüβler Plan for two different locations of plane impacts. The first location was the steel strut with the maximum compression force in the horizontal girder (see Figure 9). The second location was a reinforced concrete wall, which is part of the façade (see Figure 9). At both locations it was postulate that a small plane, a Lear Jet 23 A, will hit the structure with a velocity of 220 m/s (792 km/h). This Lear Jet has a mass of 5.7 ton and its engine has a mass of 0.2 ton.

At the first location the steel strut will fail. A further calculation of the horizontal girder without this steel strut showed that the structural safety of this system is insufficient. Therefore, a progressive failure of the whole horizontal girder due to plane impact has to be presumed.

At the second location the reinforced concrete wall is able to withstand the plane impact. The wall is damaged and shows a significant deflection, but the wall is still able to carry loads, meaning that the plane impact on the wall does not provoke a progressive failure.

2.1.2.5 Explosion

Different explosion scenarios have been considered. Internal explosions as well as external explosions have been evaluated. The size of the threat ranged from a backpack bomb to a car bomb.

Different calculation models with different precision have been applied for the assessment. With a hydrocode approach (finite element), blast loading distribution and the degree of damage to the concrete columns and concrete floors, which are key elements in the bearing structure, have been assessed by EMI. Based on this information, the possibility of progressive collapse could be assessed. The hydrocode approach has proven to be very appropriate for predicting the degree of damage and the residual bearing capacity, once the specific dimensions of a structure are known.

When local and progressive collapse can be excluded, the behavior of other elements becomes the largest hazard to people, such as the failing of weak walls or glass. These hazards have been evaluated by TNO based on engineering approaches and probabilistic functions. The engineering approach is a very appropriate approach to use also in an early design stage, even already in the sketch phase. For that purpose specifically, TNO has made a quick assessment tool, the so-called TNO façade tool. The main intent of the tool is to give directions and support to decisions in the design process before the process of detailed calculations.

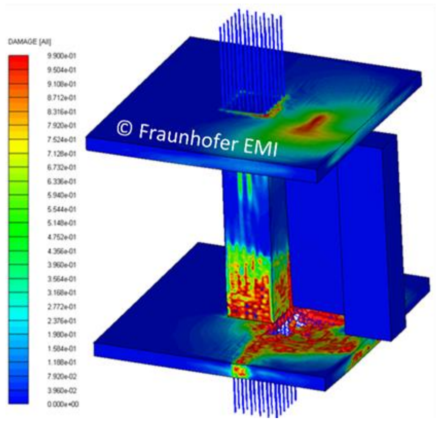

Figure 10 Hydrocode result for a detonation next to a concrete column

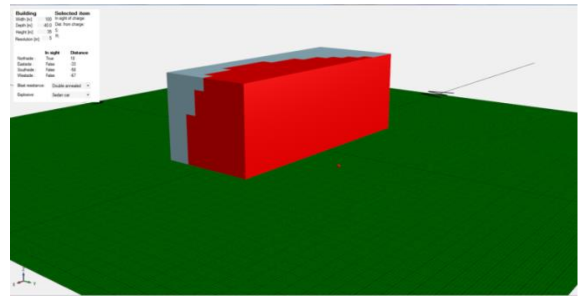

Figure 11 TNO facade tool

2.1.2.6 Biochemical threat

Two internal and one external chemical threats have been evaluated by TNO. In reality, the number of toxic and biological materials is off course numerous. In combination with the location and the attack mode, the number of possible scenarios and corresponding consequences becomes huge. The intent of the assessment was not to cover all possible scenarios but to identify weak points in the building design and to improve them. The three specific scenarios, selected by the consortium, were sufficient for that purpose.

2.1.2.7 Evacuation

In case a hazard appears, people instinctively move away from the source of danger. In this situation effective emergency evacuation of building occupants or pedestrians in the surrounding is a cornerstone to minimize serious harm to human life.

Pedestrian stream simulations nowadays consider measures to evaluate and mitigate risks in critical situations. Buildings can be designed with focus on occupant safety, making use of virtual pedestrian stream simulation. With assistance of a simulation tool, professional operators can run through multiple “what-if” scenarios , to gain experience for situations that are impossible by experiment in reality and to gather empirical data.

Building evacuation is accomplished by the Siemens “Crowd Control” environment [1, 2, 3]. It is based on a cellular automata model with attracting / repulsing potentials for destinations and obstacles (and other persons). The tool has been used several times in many applications (train main station, soccer stadium, ...). For the description and computation of the behaviour of persons in specific situations, the simulation environment “Crowd Control” uses different mathematical algorithms given by abstract, idealized models. These models respect essential impacts of the reality like different velocities of

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[1] Köster, G., Hartmann, D., Klein, W.: Microscopic pedestrian simulations: From passenger exchange times to regional evacuation. In: International Conference on Operations Research - "Mastering Complexity“, pp. 571-576. Conference Proceedings, Munich (2010)

[2] Mayer H., Hartmann D. and Klein W., Influence of Emissions on Pedestrian Evacuation. International Conference on Pedestrian and Evacuation Dynamics, 2012; 351-360

[3] Reuter V., Bergner B.S., Köster G., Seitz M., Treml F. and Hartmann D., On Modeling Groups in Crowds: Empirical Evidence and Simulation Results Including Large Groups. International Conference on Pedestrian and Evacuation Dynamics, 2012; 835-846

persons, the dependency between velocity and density (Weidmann diagram[4]), and predefined routes for pedestrians from their sources to their destinations as well as place and time of person generation and disappearance. Further aspects like age, weight or gender of persons are considered in a statistical approach. Several runs of the simulation with randomized initial conditions and person parameters are performed with variable values. Here, values and parameters known from real scenarios and originating from different information sources, like textbooks and academic publications are taken as input values for the corresponding simulation statistics.

Based on these prerequisites, the Siemens pedestrian simulation environment “Crowd Control” was further developed in the ELASSTIC project, in order to evaluate how down-time after disasters in urban and building infrastructures can be minimized through increased resilience or means of fast recovery. Here, we propose different simulation models, as part of a building management system (BMS), which allows the simulation and therefore the analysis of disaster impacts (by category) and thus provides basis for recommendations on how to improve a resilience sensor-based virtual building management system.

2.2 Extended BIM technology (BIM+)

BIM stands for Building Information Modelling; sometimes also referred to as ‘Building Information Management’. In the base, BIM is about data. It is a collective term to highlight the industry’s movement from paper based operations to data based operations. But BIM can be more. BIM is a collection of virtual objects with properties and relations. Because a computer has semantic awareness of the objects, intelligent operations can be performed on the data. Thus, new doors are opened for more efficient and intelligent processes. This is interesting for the design process for safe and secure buildings. It is best to take safety and security along from the early design phase. BIM can support this, by bringing together different technologies and by coordinating the communication.

The ELASSTIC concept consists of four main clusters of technology:

- Building Information (BIM)
- Simulation models
- Sensor information
- Multi Criteria Analyses’ (MCA)

The ELASSTIC concept is about the communication between these four main technology groups.

[4] Weidmann, Ulrich: Transporttechnik der Fußgänger – Transporttechnische Eigenschaften des Fußgängerverkehrs (Literaturauswertung) / IVT der ETH Zürich. Zürich März 1993 (Schriftenreihe des IVT Nr. 90) – Forschungsbericht

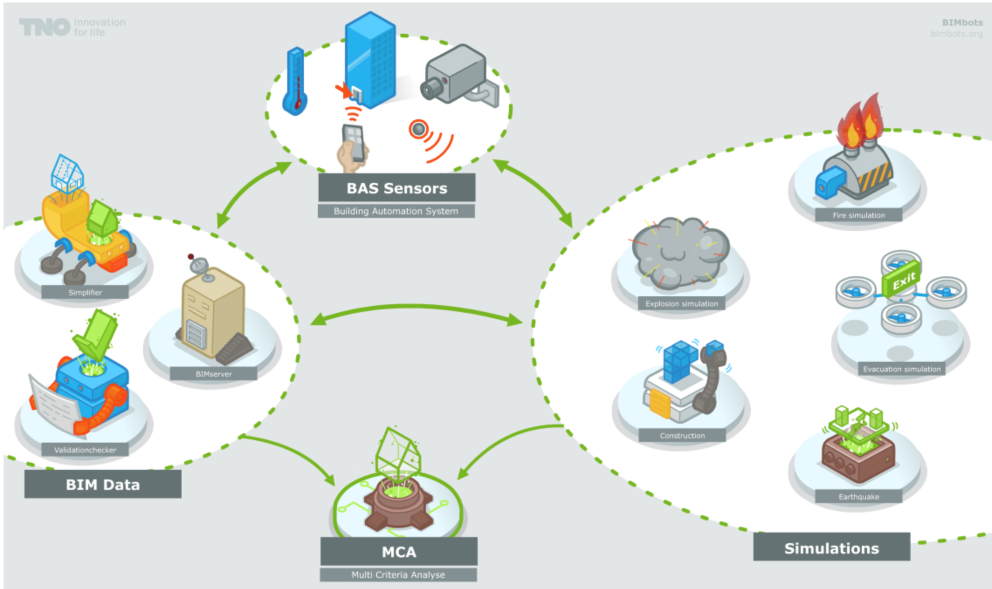


Figure 12 Communication of BIM with other technology groups

The ideal situation would be if simulation models (after a first configuration) can be run in an automated, autonomous way without human interference, and that the output of the simulations is automatically fed into the MCA tool to show the results in terms of the predefined Key Performance Indicators of the design. Then this ELASSTIC BIM concept makes it possible to have immediate feedback on the performance of the design without unnecessary delays. In the ELASSTIC project a good step forward was made toward the realization of the ELASSTIC BIM concept. A proof of technology was build and a use case was tested.

In the ELASSTIC project several services were used to perform operations. The setup of the built proof of technology is shown in the image in Figure 13.

At the core of the workflow a BIMserver.org instance is used (with the bimvie.ws GUI plugin). When data complies to certain model checks, triggers are send out to a clash detection service; a furniture placer; a validation checker; a simplifier; and the explosion simulation. These services can then trigger the evacuation simulation; a (very simple) fire simulation and a COBie exporter. In the end several services can update the viewer. The MCA link is not shown in this BIM focused picture.

During the ELASSTIC project we found that there can be several returning loops in this setup. By using correct model checks, these loops will not trigger each other into an endless loop.

As you can see in the image, several ‘support’-bots were used to adapt the BIM data and make it available for the simulation models.

The ‘simplifier’ service, the validation checker and the furniture placer are all examples of implementations that perform automated actions on data to make it suitable for the simulation models.

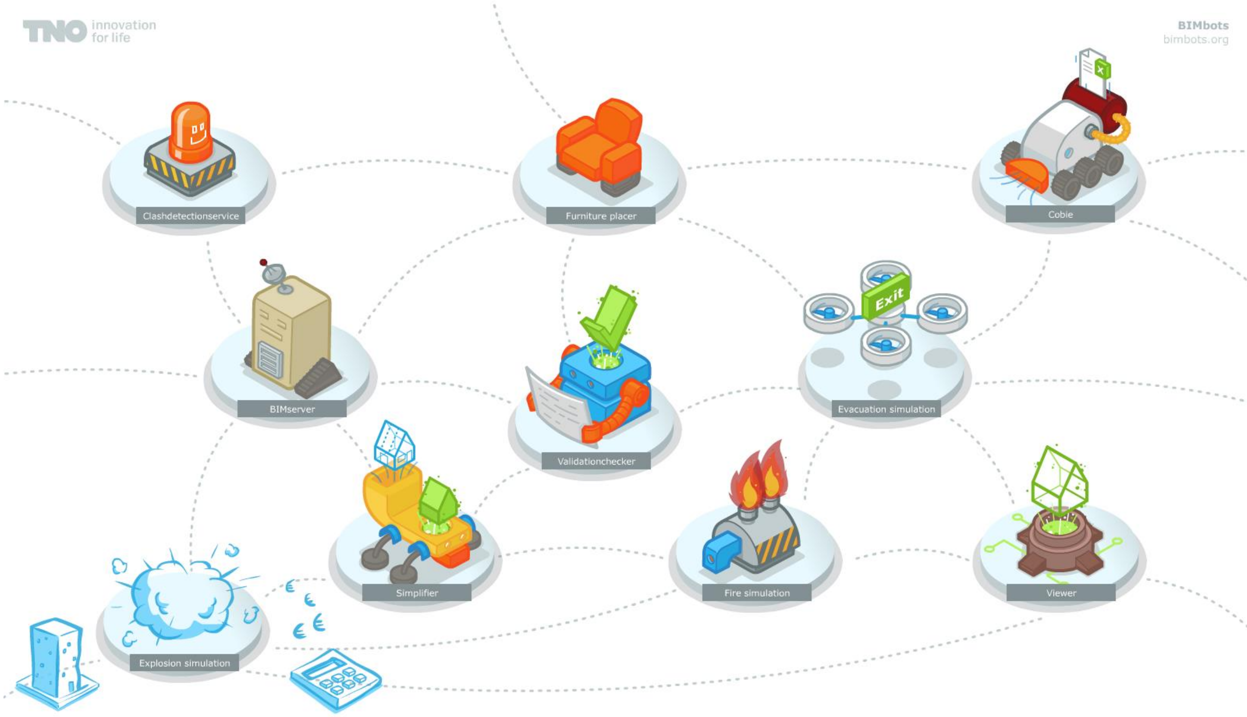


Figure 13 The ELASSTIC BIM ecosystem

During the ELASSTIC project the focus was on running simulations on the IFC (BIM) data. Most of the simulation models weren't capable of running in an online (cloud) environment. The triggering of the simulation models therefore went to a void. Some simulation models avoid this by polling for a new revision om the BIM gateway (BIMserver) every minute (or other timeframe). This obviously brought a high load of traffic and makes the BIM gateway vulnerable for traffic overload.

The 'supporting services' (furniture places, validation checker , simplifier) did use the trigger function and proved the workability of the concept. In general terms these services pre-process the data to optimize the transfer to the simulation tools.

The general consensus in the project is that running the simulation models online is a lot of work, but not a technical challenge. Therefore the priority of actually accomplishing this was relatively low.

The ELASSTIC BIM concept proved to have great potential to the industry. Due to the automation of simulation models (with or without supporting services) the designer is provided with direct feedback of the performance of the building during the (early) design phase.

To optimize the usability of this concept additional features are introduced like model-checking, pre-processing of data (called 'supporting services' in this report), post processing of data (in this project to facilitate the MCA tool), advanced query/filter functions, etc.

These additional features facilitate the usability for simulation tools to use the ELASSTIC BIM concept, and BIM in general.

2.3 Smart and reinforced structural elements for a resilience monitoring system

The purpose of the EC research project ELASSTIC is the improvement of the resilience, the safety, and the security of a large scale multi-functional building complex. Achieving the required safety of the users of the structure, a certain physical and mechanical robustness of the building structure is needed. It is a relevant issue to make the load carrying structure of a building resistant not only to standardized design loads, which is required to obtain permission to build such a construction, but also to extreme loading scenarios. Especially highly exploited structures and buildings with a strong societal, economical and political impact are more vulnerable and thus in great danger. Loadings with high pressures and forces and small loading times (impulsive loadings) become relevant. Since there are no European standards available, which provide a quantification of such scenarios for the design process, scientific approaches offer a good possibility to design such a complex safe and resilient.

One goal of the ELASSTIC project is to design structural members with an improved resistance. This is particularly relevant for essential load carrying members in a construction.

An improved structural resistance of structural members is linked to several characteristics, namely a high tensile strength, a high compressive strength, a high fracture energy (energy absorption capacity), and an improved softening behavior. Through these characteristics the possible damage in case of an extreme event can be reduced, resulting in a higher residual cross section of the load bearing elements and thus a reduction of the possibility of partial or complete collapse of the structure.

A second goal of the smart elements is the integration of a sensor system into the elements, which receives signals in form of pressure and temperature date during a hazardous event. This data will run through an internal evaluation tool that evaluates the happened scenario and transmits information concerning the behavior of the structure (damaged or not damaged) to the BMS and BIM server. This information will be used by the dynamic evaluation system developed within ELASSTIC, as well.

So, the target is to create structural elements with high structural resistance and with integrated sensors. This task was done by EMI. The following boundary requirements were set for the development of the so-called smart structural element:

- High robustness
- Integration of sensors
- Easy fabrication
- Cheap fabrication.

2.3.1 Concrete Development

For achieving all necessary properties, a material research was carried out. Different concrete types were taken into account and their material behavior was investigated. From the mechanical point of view as well as concerning the cost and the flexibility in further developments, the fiber reinforced UHPC was the material of choice for this project, because of its improved mechanical performance. An extensive material development with quasi-static and dynamic mechanical characterization and the characterization of the temperature behavior was accomplished. The scope of the material development was focused on the requirements regarding the resistance of the smart elements in case of extreme loading scenarios and related high pressure and temperature loadings. Within the test series, the UHPC mixture was varied, for both the types of fiber and their percentage in the concrete mixture. Both quasi-static and dynamic tests under clearly defined loading conditions have been executed. The test procedures under quasi-static loading require low loading velocities and special specimen shapes and dimensions. These boundary conditions are described in European test standards for solid concrete. The tests are carried out by using hydraulic test facilities. The characterization of concrete materials under dynamic loading is not standardized internationally. However, scientific acknowledged methods are applied to determine the essential properties of the materials in laboratory experiments under ideal boundary conditions.

Figure 14 exemplary shows some results of the characterization for the quasi-static tensile strength and the Young's modulus. The figures show the dependence of the tensile strength on the compressive strength (left), the fiber length and the fiber volume fraction, respectively (middle). All investigated mixtures are taken into account and marked in the images. Detailed information about the mixture composition and the entire material research study is documented in D3.4[5]. The tensile strength primarily depends on the fiber length and the fiber reinforcement ratio. The fiber reinforcement ratio is an important factor regarding the workability of the concrete. The higher the fiber content, the more difficult the workability of the concrete. Steel fibers deliver the best results concerning the workability and have no significant influence on the compressive strength.

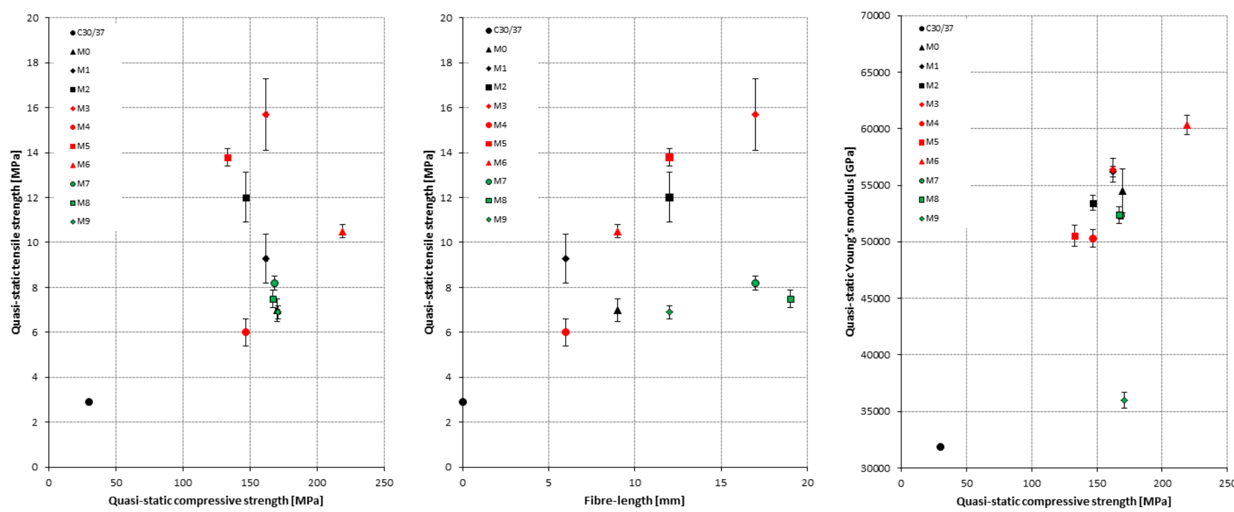


Figure 14 Left: Quasi-static tensile strength for all mixtures, middle: Quasi-static tensile strength for all mixtures with regard to fiber length, right: Quasi-static Young's modulus for all mixtures with regard to compressive strength

In the end a protective layer of UHPC with integrated fibers of steel and PVA was identified being the best mixture to achieve all properties, which are indispensable in this project. The synthetic fibers should guarantee a better behavior under high temperature loading and contribute to improved material properties. The steel fibers improve the mechanical resistance in terms of an increase of the tensile strength and the fracture energy.

2.3.2 Design of smart elements

The smart elements, applicable as wall-, slab- and column-elements, show a layered set-up containing conventional reinforced concrete as core material and a specific fiber reinforced UHPC as protective layer. The protective layer, with its high strength and high energy absorption capacity, guarantees the high robustness in case of extreme loadings. Figure 15 shows schematically the design of a smart element, which is fabricated as a wall in this case. The protective layer works as a lost formwork for the smart elements. Thus, a semi-pre fabrication becomes possible.

[5] Oliver Millon and Anne Kleemann, Development of high resistant smart elements, D3.4, 23/04/2015

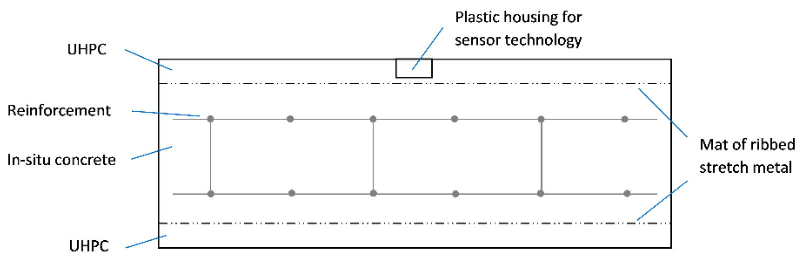


Figure 15 Sketch of a smart element-construction (wall panel in sectional view)

2.3.3 Behaviour of the single elements under extreme loading events

In comparison to the standardized quasi-static design loads, the loadings from extreme events are generally characterized by a high loading pressure (in a range of several MPa up to GPa), which occur in small loading times (within µs to ms). These loadings are summarized as dynamic loadings, since the force acting on the structure and the material change over the loading time.

Dynamic loadings, like detonation, impact or penetration, are often related to as stress-wave loading. The loading process can be explained as documented in Figure 16, that shows the process of the stress-wave propagation within a flat structural member. In case of a close-in detonation the loading is characterized by stress-waves leading to damage of the concrete microstructure (cracking and fragmentation). On the attack face, the pressure exceeds the compressive strength of the material. A compressive damage zone will arise. The stress waves are transmitted by the material through the structure. At the rear face, these waves reflect as tensile waves, causing tensile failure. This tensile failure materializes as spalling. The higher the strength and energy absorption capacity of the material, the smaller the damaged zones will be. When the charge is large enough or the standoff is small enough the two damaged zones will merge and breaching occurs.

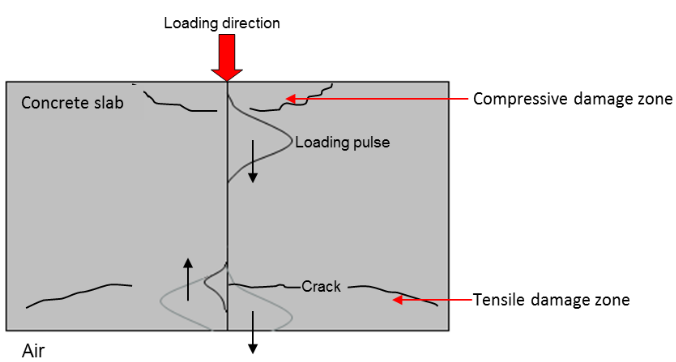


Figure 16 Loading process of a structural member: stress waves and damage from a detonative loading

2.3.4 Dynamic tests on smart elements

Several dynamic experiments in the form of detonation tests were carried out to evaluate the structural behavior of the smart elements, fabricated as wall- and column-elements, and to determine their residual load bearing capacity, tested through further quasi-static tests. During the tests, relevant loading scenarios were simulated. Figure 17 shows a general detonation test setup of a wall structure, which is fixed on a supporting frame. The charge is located in front of the center of the smart element.

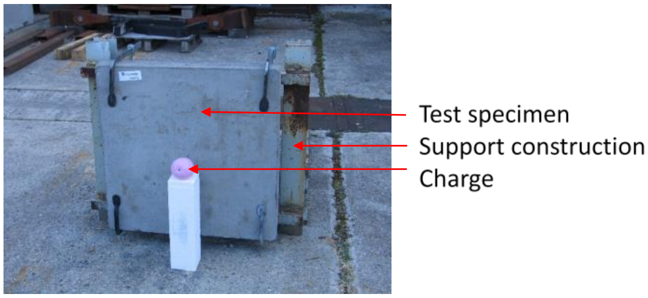


Figure 17 Test set-up of detonation test on a smart element-wall

In all tests carried out, the front face only showed small abrasion. However, the rear face showed a significantly larger damage, which can be observed in Figure 18. The rear face had a spalling area and the reinforcement was exposed to a large extent. The observed damage results from the shock wave loading, caused by the detonation.

Figure 18 Damaged Elements after detonation tests, above: front face, below: rear face.

2.4 Smart evacuation system with real time information on the safety, security and resilience of infrastructure

The smart evacuation system evaluates how down-time after disasters in urban and building infrastructures can be minimized through increased resilience or means of fast recovery (cf. Figure 19). We propose different simulation models for hazard and pedestrian evacuation, as part of a building management system (BMS), which allows the simulation and therefore the analysis of disaster impacts (by category) and thus provides basis for recommendations on how to improve resilience sensor-based building management systems. This new type of virtual vBMS will be used for an experimental performance analysis of multifunctional sensing elements regarding relevant loading scenarios (defined by the consortium). Moreover, a “demonstration” of the realization of different hazard scenarios and of the virtual building management system (vBMS) will be explained: on the one hand, this demonstration will be explained in this report. On the other hand, this prototype was shown in different ELASSTIC meetings[6, 7, 8, 9].

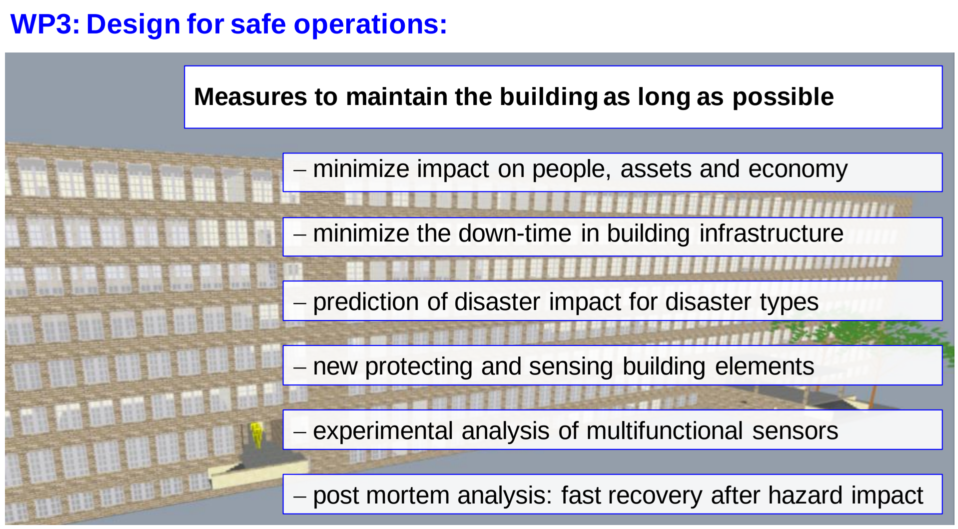


Figure 19 Overview on the main activities related to design for safe operations

2.4.1 Hazard Simulations

Within the European ELASSTIC project, Siemens AG developed and realized several models for the coupled simulation of hazards and pedestrians. The corresponding simulation results are significantly relevant for the design, construction and operation of larger building complexes embedded into an urban infrastructure. Several demonstrations have shown applications of hazard and person stream simulations for the specific showcase scenarios developed by the ELASSTIC consortium (multifunctional office complex in the city centre of The Hague). This is the building design we bear in mind when looking closer at some specific aspects of the hazards. In addition to that design, coupled pedestrian and hazard simulations were shown also for further, different buildings in Munich or Zug / CH, e.g.. The concrete aim of this hazard simulation is the computation of effects of flooding, fire/smoke, and virtual explosives scenarios on the evacuation of buildings. Buildings together with their internal structures like walls, rooms, levels and stairs will be influenced by these hazardous scenarios.

One focus of the hazard simulations is the coupled simulation of pedestrian and flow dynamics. A suitable physical model for the flooding of buildings is given by the two-dimensional shallow water equations as described in Toro[10]. The shallow water equations in 2D describe a free surface flow in the unknowns u, v (velocities in x and y directions) and the water height h. For the flooding of buildings, the shallow water equations are solved on each floor of the building separately, and sources and sinks serve as links between the floors. In order to work with larger topologies over a longer water simulation time,

[6] Munich Oct. 2014: demonstration of a fire simulation
[7] Brussels Jan. 2015: vBMS demonstration
[8] Amersfoort March 2015: water simulation demonstration
[9] Den Haag ELASSTIC end workshop, April 2016
[10] Toro E.F., Shock-Capturing Methods for Free-Surface Shallow Flows. Wiley, 2001

one approach was to utilize a locally adapted grid. Here, the simplified quadtree approach from Liang[11] was adopted. In a second approach, a bachelor thesis was set up, which transformed the entire algorithm to a graphical processing unit[12]. Based on these models, a realistic example was shown for a virtual building developed in ELASSTIC demonstrating the impact of different flooding scenarios on the pedestrian dynamics depending on environmental conditions, e.g. the water level[13].

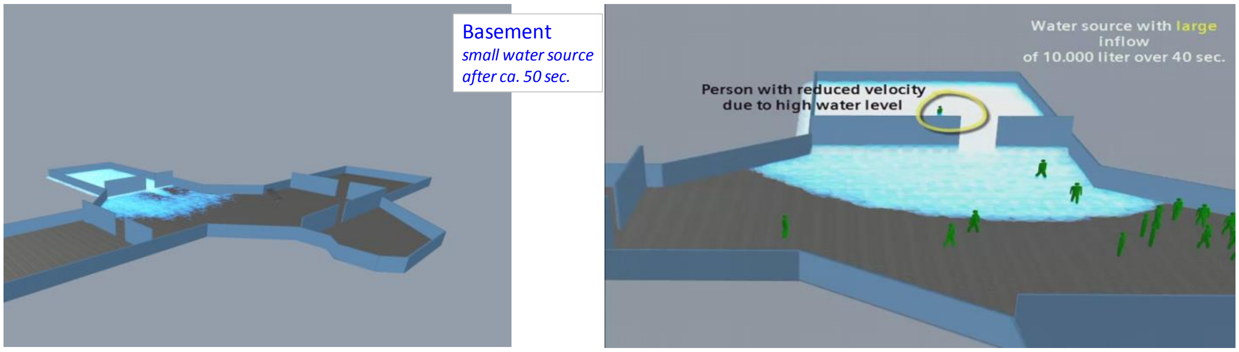


Figure 20 Flooding scenario shown in the 3D visualization for the Siemens Munich Office building

A further aspect of the hazard simulations in the evacuation environment is the coupled simulation of pedestrian and fire / smoke hazards. In Siemens „Crowd Control“, different models for a fire simulation are realized:

- a simple fire propagation model
- a medium sized fire simulation model
- and an external, detailed fire simulation model

Furthermore, the fire simulation model is coupled to the pedestrian stream simulation concerning the behaviour of pedestrians in case of fire. The "simple fire propagation model” offers the following functionality:

- Graphical UserInterface GUI: define the place and size of a fire source in an arbitrary part of the building
- define ignition time of the fire
- define speed of fire/smoke spreading

During the simulation, the fire/smoke spreads over time with respect to the following behaviour:

“Fire/smoke” is modeled as:

- dynamically growing obstacle; with a fixed growth rate over time
- the growth rate depending on material; i.e., material parameters are considered
- the cells rendered non-accessible can be interpreted as fire, smoke, high temperature, gas

[11] Liang Q., A simplified adaptive Cartesian grid system for solving the 2D shallow water equations. Int. J. Numer. Meth. Fluids, 2012; 69; 442-458

[12] Bachelorthesis with Rapperswil: “Acceleration of water simulation algorithms on a GPU”, 15.06.2015, Hochschule für Technik Rapperswil, Switzerland

[13] M. Paffrath, C. Frey, W. Klein, H. G. Mayer: Evacuation of buildings in case of flooding; Proceedings of the International Association for Shell and Spatial Structures (IASS) 2015

The following restrictions of the simple model have to bew taken into account:

- no inclusion of fluid / gas dynamics is taken into account
- nor gas properties (noxiousness etc.)
- the “fire obstacle” occupies the entire height of the level

Concerning the simulation of people behaviour in case of fire / smoke, one aspect is the fact that persons try to avoid smoky areas leading to a proposal of the rerouting of persons by the “Crowd Control” algorithms. Other specific simulation models of the pedestrian behaviour are chosen due to literature studies and statistical data.

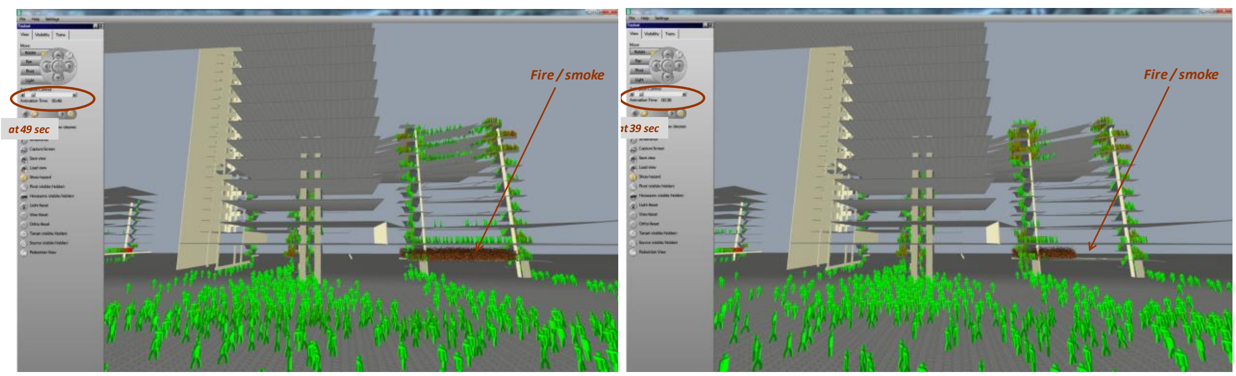


Figure 21 Fire expansion for Ribbon building with rerouting

The fire scenario in Figure 21 the location of a fire and its spreading near a stair case and the ground floor. After ca. 39 sec., the size of the fire / smoke blocks one / both stair cases; respectively.

A third aspect of the hazard simulation within the “Crowd Control vBMS” environment is the realization of explosion scenarios. On one hand, a virtual explosive hazard event can be generated in the graphical user interface. This virtual explosion influences the state of the building near the explosion, and therefore, the routing of the involved persons as well as the behaviour of the persons themselves. Nevertheless, it should be mentioned that, due to the lack of available data, the simulation model used here is a first basic model implementing only some fundamental hazard effects.

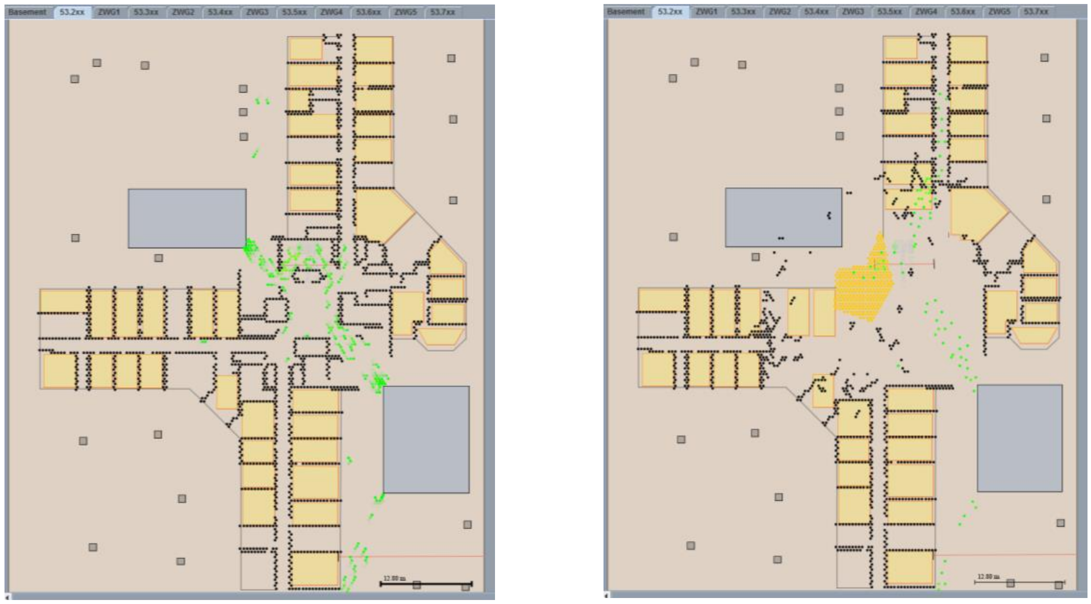


Figure 22 Explosive scenario defined in the GUI before (left) and after (right) the explosion

2.4.2 Integration of the evacuation simulation into a virtual Building Manamgent System (vBMS)

The principal idea is that a building will be equipped with a variety of sensors to detect the manifestation of certain hazards. Depending on the type of hazard, one or more sensors will provide relevant data, which have to be analyzed. Therefore, a central processing unit is needed to integrate the readings of all sensors and interpret them correctly. In addition, once a hazard has been detected, adequate measures should be initiated to mitigate the influences of hazards. This central unit is called virtual building management system (vBMS). Originally a building management system is focussed on energy, comfort, safety and security management of a building and therefore is coupled to the installed systems, e.g. to HVAC and/or lighting. In addition, the vBMS also serves as basic platform for user interaction, i.e. the status of the building (as determined by sensors) is displayed in an adequate manner to allow for profound decisions by the facility manager. For example, the location of fires will be visualized on the building management station and, as a consequence, some actions will be performed automatically (e.g. activation of sprinklers), while others will be initiated by humans (phased evacuation). All relevant sensors and actuators will be linked to the building management system.

In order to react on unknown situations, the BMS was enhanced with simulation disciplines to a vBMS, which can be used to pre-calculate the optimal actions for any evolving situation. An example for such an integrated software application is a pedestrian simulation, which can be used to react on arbitrary changes in the accessibility of the building. For example, if certain parts of the building are affected by hazardous conditions, the simulator will calculate a new optimal route out of the building. This can be done for groups of persons (e.g. floor occupancy) or even individually. Afterwards, the vBMS can use the connected actuators (like dynamic exit signs, or Smartphone connections) to feedback the safest evacuation route. A framework for a vBMS with these new features was developed within the ELASSTIC project. This generic prototype is based on the software developed by Siemens Corporate Technology (CT) and can later be integrated in any type of existing building management system. With a demonstrator the functionality was shown at the end workshop in Den Haag. In particular, the following features will be integrated in a “Crowd Control vBMS”:

- Interconnection to a building information model (BIM)
- Communication and interoperability with new types of sensors
- Interconnection to a pedestrian stream simulation tool
- Determination of situational dependent, dynamic user specific evacuation routes

Figure 23 Online sensor values during a simulation in the „Crowd Control“ GUI for the ELASSTIC Ribbon Building

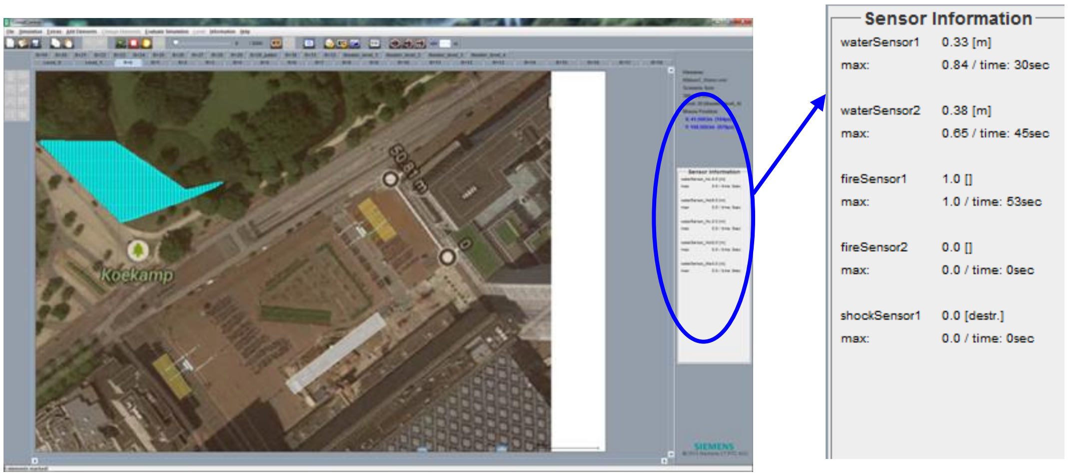


Figure 23 Online sensor values during a simulation

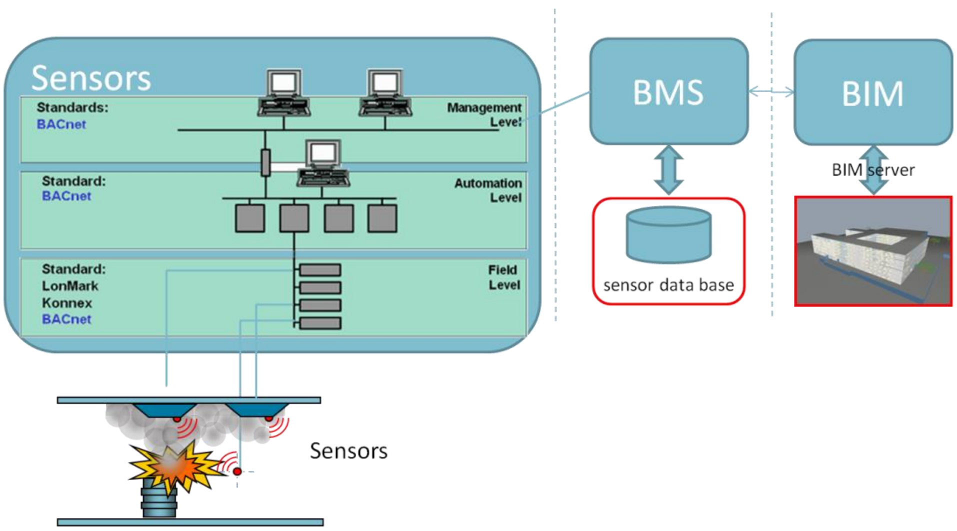


Figure 24 System architecture of Siemens „Crowd Control vBMS“

2.4.3 Legal and ethical aspects related to monitoring system

The ELASSTIC concept of a dynamic evacuation system with monitoring has to meet legal and ethical requirements. One has to comply with ethical principles and relevant national, European Union and international legislation, e.g.:

- Charter of Fundamental Rights of the European Union;
- European Convention on Human Rights.

The requirements have been outlined and analysed in the ELASSTIC project by INCODE. Questions to deal with are for instance:

1. Knowledge of location of all persons in building (by IT)? E.g. anonymous data or optional subscription. This is a privacy related issue.
2. Knowledge of location of disabled persons? E.g. anonymous data or optional subscription. This is also a privacy related issue.
3. This knowledge at 24 hours,7 days; E.g. anonymous data or optional subscription; privacy related issue.
4. Operating/storing these data: where, when, how long?; Optional subscription to data use. This concerns data protection related issues.
5. System breakdown in fire: data availability still works?: Disclaimer by system operator; Legal related issue.
6. Plans and responsibilities during fire? Specified by local fire brigade: Legal related issue.

Pursuant to Directive 95/46/EC, personal data comprises "any information relating to an identified or identifiable natural person. The ELASSTIC-concept must comply with the next requirements:

- data protection provisions on the processing of personal data in ELASSTIC fulfill with the Council of Europe Recommendation ;
- any data processing activity must fulfill at least one of the criteria for making the processing legitimate. These are to be found in the exhaustive list in Article 7 Directive 95/46/EC;
- data processing operation(s) comply with all the principles in Article 6 of Directive 95/46/EC

Pursuant to Article 33 of the proposed regulation the ELASSTIC building managers carry out a data protection impact assessment. A Decision Tree format in view of determining whether a full-scale or a small-scale DPIA (Data Protection Impact Assessment) should be selected in function of data processing.
Finally the conclusions reached in ELASSTIC were:

1. The ELASSTIC operators and public authorities, comply with their internal safety and security provisions, which are based on their internal regulations and local laws to which they are subject. These safety provisions refer both to measures to prevent a crowd disaster from occurring and to measures to mitigate the disaster to reduce casualties.
2. The needs of vulnerable groups, such as the disabled, have to be accommodated as much as possible in the crowd management process has been considered in ELASSTIC use cases.
3. Every personal data processing operation (video surveillance, RFID, smartphone applications) has a clearly designated controller. In the framework of ELASSTIC, due to the numerous actors involved in crowd management, different controllers are expected to compose the "Smart Spaces" and thus every one of them must be clearly identified.
4. The ELASSTIC controller:
    a. ensure compliance with all the principles of data protection: data minimization, purpose limitation, adequate retention period, data accuracy, security and confidentiality of processing.
    b. before personal data processing operations commence, she/he justify the necessity and proportionality of each operation. The margin of appreciation of the authorities

responsible for crowd management is wider in cases of evacuation in comparison to the prevention stage.

c. guarantee the rights of data subjects (information, objection to processing, right to access, rectification, erasure or blocking).

2.5 Multifunctional resilient large scale urban complex: the ELASSTIC complex

The ELASSTIC complex has been designed from an initial multifunctional program as illustrated in Figure 25.

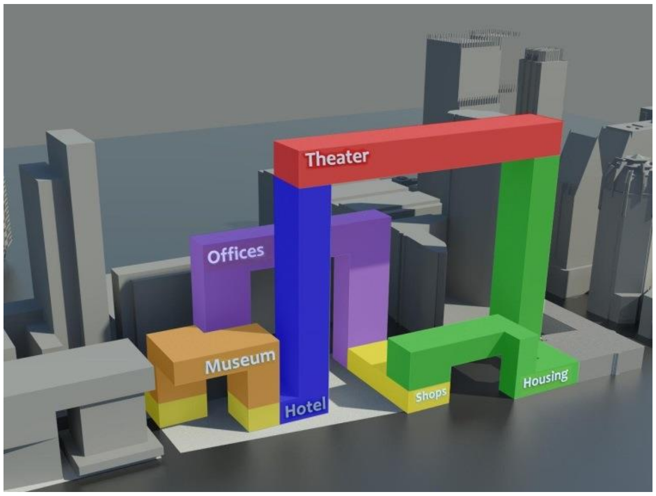


Figure 25 Multifunctional program of the ELASSTIC project

The design was carried out in three stages:

1. The BENCHMARK DESIGN was the initial basic design that all partners agreed upon to develop further. See Figure 26
2. The 1st COORDINATED DESIGN (1st Quantitative Design) was the complete design alongside the structure and the services designs. See Figure 27. This design was the basis for the hazard studies and simulations.
3. The 1st Integrated Design (2nd Quantitative Design), was a modified version of the 1st Coordinated Design with the integration of certain design decisions taken from the results of the experimentations and simulations of the various hazard scenarios. See Figure 28.

An example of one of the modifications made was the decision to incorporate blast-proof glazing system on to all of the glazed facades of the project. The change is illustrated in the two images in Figure 29, the image on the left being the 1st Quantitative Design and the image on the right being the 2nd Quantitative Design. The detail is from the Theatre Bridge over the largest arch.

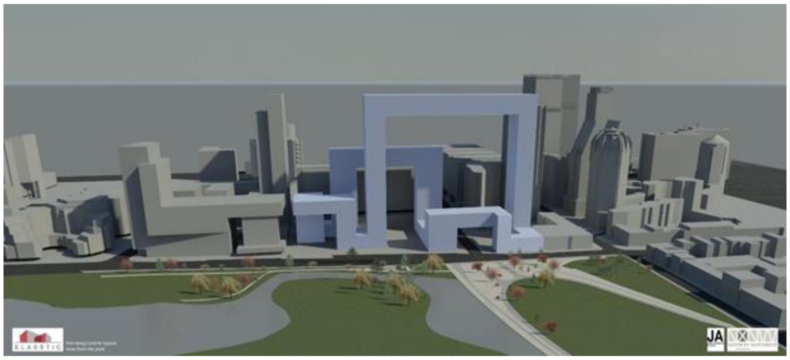


Figure 26 Benchmark design

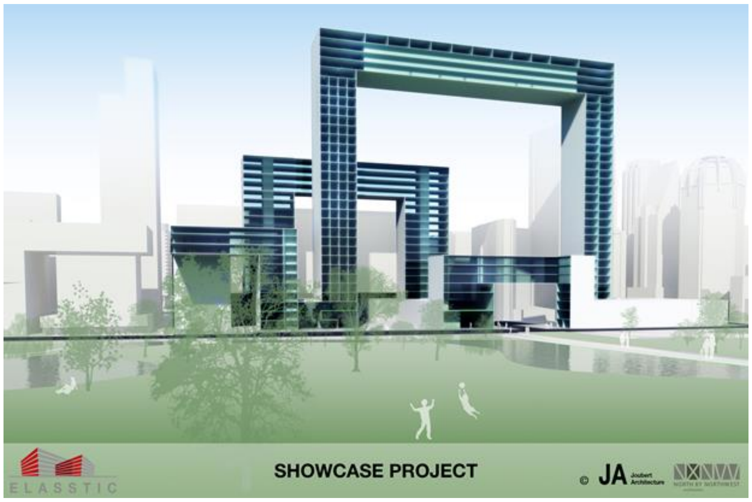
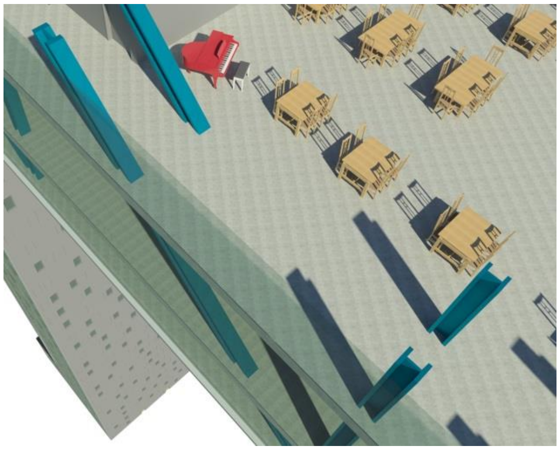
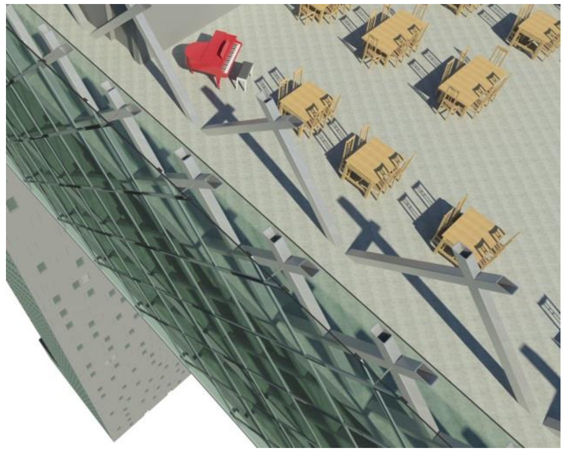


Figure 27 1st coordinated design

Figure 28 1st integrated design (or 2nd quantitative design)



1st Design Theatre Bridge Façade



2nd Design Theatre Bridge Façade

Figure 29 Multifunctional program of the ELASSTIC project

2.6 Recommendations for regulatory framework

During the working time of the research project, many different topics were addressed. The objective of this section is to objectively show if a regulatory framework process should be initiated by EU policy makers or not. From the beginning it was clear that this question cannot be answered in general because too many different topics were addressed within the scope of the whole project. Therefore, the research team decided during one of its general assemblies to answer this question for selected topics separately. These selected topics are:

- Execution of risk analyses,
- Extreme wind loads on buildings,
- Structural performance during earthquakes,
- Structures under fire,
- Plane impacts on buildings,
- Explosion in or close to buildings,
- Biological or chemical hazards,
- Flooding,
- Evacuation and its simulation,
- Multi-Criteria analysis,
- Building Information Modelling (BIM),
- Sensors and their collected data.

For any of these 12 topics one or more interviews with different experts within the research team were performed.

During these discussions it was worked out that the research team recommends to the EU to initiate regulatory activities regarding risk analyses of buildings and time-temperature-curves for fires in buildings initiated by an impact of a plane, a truck or a car.

For the other topics treated during the ELASSTIC-project, the research team sees no need for regulatory activities. The reasons are diverse, but for many topics like earthquake, fire or wind the EU has already established codes, which reflect well the state-of-the-art. Other events are too seldom to be codified or the developments are not mature enough to start a regulatory process, e.g. dynamic evacuation or BIM. For both mentioned topics the research team recommends to the EU to start further research activities because both topics have the potential for further innovation and application in practice in the near future.

3 Potential Impact

3.1 Impact

The world's population living in cities is rapidly increasing and with that the urban built infrastructure. This tendency is observed in Europe as well. The growing world population, the ongoing urbanization, the ever-increasing size, height and complexity of large scale built infrastructure leads to higher risks with respect to natural and manmade threats. In case of a real incident, this leads to more casualties, injured people and damage.

Such incidents are realistic, given the trends in the world. Climate change and the political instability in the world give rise to extreme events like flooding, extreme wind and terrorist attacks. Recent examples are the bomb attacks in Brussels (March 2016), the flooding in several European countries in the winter of 2015/2016 and the earthquake in Greece in November 2015.

Such extreme incidents are not often considered in a design. Several reasons can be identified for this omission:

- The extreme incidents have a low probability compared to other issues designers have to deal with it. The extreme incidents are therefore not on the priority list. Indeed, many parties think that it will not happen to them.
- The problem is complex, and parties do not know how to incorporate measures against reasonable costs.

Evidently, there is a need for a comprehensive approach 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 illustrated and disseminated by the ELASSTIC consortium that the most effective way to include safety, security and resilience in a design, is when the topic is considered from the beginning, i.e. in the planning and design phase of buildings and complexes. And this also counts for urban design. Decisions in each design stage do influence and/or limit the possibilities to include safety, security and resilience.

By doing so, it is expected that the design of urban areas and large scale complexes will be improved and better prepared for extreme events resulting from either natural hazards or manmade hazards. This is not about 100% protection, but about regeneration capacity and being able to bounce back to normal. Furthermore, it is about saving lives that not necessarily need to be at stake. That would happen if infrastructure would make the consequences of a hazard more serious due to a vulnerable behaviour.

Safety and security experts need to be part of the design team in order to make proper decisions and to be able to explain what the possible consequences of decisions are. For supporting this process, the ELASSTIC project has developed, created and tested several approaches and tools, which help to organize the design process better. The main results are the following:

1. A comprehensive/systematic approach and tools to design safe, secure and resilient large scale building complexes, including an Multi Criteria Analysis tool for judgement and assessment of the design. After all, a design will be the result of choices and tradeoffs.
2. Extended Building Information Model - BIM technology. BIM is more and more adopted in European countries to use for designing and saving all data about a building. Extending the use of BIM by giving it a central function in the communication in the design process and by realizing

links with different calculation tools, increases the value of a design in BIM significantly and will make the design process more efficient.

3. The development of smart and reinforced structural elements that incorporate at the same time a high performance regarding energy absorption capacity, and a sensoring function for real live information.
4. Smart evacuation design and system based on a resilience monitoring system with sensors and smart BMS-system, live information and reliable evacuation simulations.
5. Development of supporting tools for analysis of hazard scenarios.

As such the project has made a tangible and significant contribution to supporting public bodies and other stakeholders in identifying the correct course(s) of action, prioritizing monetary and personnel resources to initiatives, policies and interventions where they are most needed.

The exact impact of ELASSTIC is hard to quantify, but is certainly:

- Provide urban environment managers, building owners and operators with urban resilience interventions for the built environment at different development stages to limit the risks of demolition or structure collapse, resulting in infrastructure protection and potentially saving human lives in the case of a disaster event.
- Build capacities of public bodies and relevant urban environment stakeholders on resilience and disaster preparedness and management concepts for the built environment enhancing this way the uptake of evidence-based decisions.

As a result, the socio-economic impact of an extreme event, and the loss of lives are reduced.

3.2 Main Dissemination activities

All partners believe that dissemination is a crucial activity for the project to make the impact as listed. All partners have been involved in a series of external dissemination activities, stimulated by the dissemination manager and supported by the dissemination team of Uniresearch. These dissemination activities are monitored during periodic progress meetings with the entire consortium. The original goal for dissemination was to organize at least six presentations at conferences and organize an end workshop to present the results of the project to a wider public.

During the course of the project the ELASSTIC team has given/ made:

- 30 presentations at a wide variety of conferences and events
- 6 Articles published in journals and proceedings
- 13 press-releases

The project website (www.elasstic.eu) has been set up, and continuously been updated.

Core information:

- Over 6,000 visitors of the website
- Over 9,000 Pages watched by visitors
- Visits from the EU countries and from:
  Visitors from US, Brazil, Russia, China, South Korea and Japan

In total three flyers have been made for distribution to interested parties. The third one was a digital interactive presentation, including movies, pictures and explanations on the methods and tools (in Prezi), including also links to illustrating videos.

An end workshop was organized. There was a lot of interest for the workshop, given the number of participants and the number of expressions of regret from persons who were not able to come.

Social media like twitter was used intensively by project partners to track attention from external parties.

3.3 Exploitation of results

In the future more projects will be designed under so-called DBFMO contracts (Design-Build-Maintain-Finance-Operate), or parts thereof. For DB-projects the improved integral design with BIM will give a competitive edge, and for the MO-element the correlation between BIM-BMS is very valuable. First as a design tool, and later on as an operational and maintenance tool.

The market will mainly be European tenders for Construction projects. The estimated market for engineering will be in the range of hundreds of millions of euro's.

For all partners of the ELASSTIC project counts that they will strengthen their special knowledge about safety and security in building complexes during the project. Because of the increasing importance of safety and security, this additionally gained knowledge will enhance the competitiveness of all partners on the consultancy market.

Thanks to the dissemination the project results, all partners will be regarded as competent partners for the realisation of ambitious, resilient building complexes. Therefore, all partners will get additional consultancy orders on a market where only a few companies or institution can provide these specific competence references.

With the additional safety and security products developed in ELASSTIC, new opportunities are created on the market of smart building technologies. The buildings can be made even more smart. With new sensor technologies and smart evacuation systems we are able to minimize risks in the early planning phase and by permanent building monitoring with adaptive evacuation routes in the phase of usage. Currently the size of the national market e.g. in France and Germany is in the order of 500 M€/yr. The building technology market is still a push market, but with the ELASSTIC aimed impact on future legislation and the proven benefit of resilient and safety integrated design, a redirection towards a pull market could be started.

4 Website and relevant contact details

www.elasstic.eu

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