Doctoral Dissertation
Doctoral Program in Civil and Environmental Enginering (31.th cycle)

Development of Virtual Cities Models during emergencies

Alessio Vallero

* * * * * *

Supervisors
Prof. Gian Paolo.Cimellaro., Supervisor
Prof. Giulio.Ventura. Coordinator
Prof. Stephen.A.Mahin. Host Supervisor

Doctoral Examination Committee:
Prof. Alan O'Connor , Referee, University of Dublin - Trinity College
Prof. Franco Bontempi , Referee, Università degli studi di Roma 'La Sapienza'
Prof. Anastasios Sextos , Referee, University of Bristol
Prof. Mario De Stefano , Referee, Università degli studi di Firenze
Prof. Enrico Spacone , Referee, Università degli studi 'G. d'Annunzio' di Chieti

Politecnico di Torino
March 22, 2019

I hereby declare that, the contents and organisation of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

. . . .

Alessio Vallero

Turin, March 22, 2019

Summary

Building Evacuation is an important application field of Agent-Based Modeling (ABM). This research links together structural analyses, damage scenarios, human behavior, ABM simulations and sensor based catastrophe management through multiple case studies made in California, United States and aims to demonstrate the effort that reliable damage scenarios, human behavior and risk analysis can bring in the field of Emergency Management, making simulations closer to reality. Smart sensor networks produce pervasive structural health monitoring (SHM) information. Using sensors data, mobile operating system frameworks return processed features such as attitude and heading that can be used to improve structural health awareness. Knowing structure's coordinate system a priori, even the data from arbitrarily positioned sensors can automatically be transformed to the structural coordinates, used to estimate buildings risk and improve ABM simulations reliability. To explore the use of MEMS accelerometers used by sensors built during this research to detect and characterize vibration sources in buildings, this study involved experimental data collection and machine learning algorithmic processing components.

Acknowledgements

I would like to express my deep gratitude to my host supervisor Stephen Mahin, Professor at the University of California, Berkeley. Prof. Mahin is an example of passion and hard work.

I would also like to thank Prof. Gian Paolo Cimellaro, my research supervisor, for the possibility he gave me to work on this incredible research project. During the past years he was always willing to give me suggestions and inspirations to accomplish our goals, he motivated me to keep working hard throughout my entire academic career. My gratitude is also extended to all members of the Resilience Group in Turin.

Finally I want to thank my family for their support, faith and encouragement to achieve my life goals.

I would like to dedicate this thesis to Mira, my beloved cat

Your genuine love for me, your presence in difficult times and your kindness, really gave me strength when it mattered the most.

Contents

List of Figures

List of Tables

Chapter 1

Introduzione in lingua italiana

L'Agent-Based Modeling (ABM) è una tecnica efficiente nata con lo scopo di simulare gli effetti delle decisioni prese da elementi detti agenti. Una delle applicazioni più importanti dell'ABM è la simulazione dell'evacuazione di individui da edifici o quartieri. La maggior parte dei casi studio oggigiorno si concentra sulla modellazione del comportamento umano per modellare l'evacuazione da incendi, atti terroristici o tsunami. Rimane invece finora inesplorata l'evacuazione di individui causata da terremoti, in cui sono necessari ulteriori dati sullo stato di danno all'interno delle strutture. Per risolvere questa lacuna, è stato effettuata un'attivita' di ricerca presso il PEER - Pacific Earthquake Engineering Research Center, centro di ricerca parte dell'Università della California a Berkeley. E' stato realizzato un caso studio relativo ad un edificio progettato da Forell-Ellsner, azienda di San Francisco e situato nella città di Oakland, CA. Il sito di realizzazione della struttura è ad alto rischio sismico, essendo prossimo alla faglia di Sant'Andrea. La struttura è stata progettata secondo i canoni previsti dalle normative americane relative all'acciaio con isolamento alla base (Single Friction Pendulum Bearings) e testata al Maximum Considered Earthquake.

La ricerca in oggetto intende inoltre dimostrare quanto sia importante includere scenari di danno all'interno della simulazione Agent-Based, qui ottenuti attraverso l'utilizzo del Performance Assessment Calculation Tool (PACT, software della FEMA), i cui risultati delle analisi strutturali e non strutturali sono stati utilizzati per ricavare le percentuali di componenti danneggiate in ogni piano dell'edificio. Sempre mediante PACT è stato possibile ricavare le percentuali di persone ferite o debilitate. Tali risultati sono stati realizzati su mappe di danno e collegati con un software di simulazione realizzato appositamente.

L'attività di ricerca si è inoltre concentrata a sviluppare un modello di comportamento umano basato su dati reali derivati da questionari distribuiti sia negli Stati Uniti che in Italia. L'attendibilità delle risposte è stata valutata seguendo la teoria del Planned Behavior di Ajzen (1991) [1]. Il modello di comportamento, basato sul "Belief, Desire and Intention framework" di Lee, considera invece numerosi aspetti del comportamento delle persone durante l'evacuazione causata da catastrofi naturali e tiene conto della formazione di gruppi quali famiglie o amici e della ricerca di persone care da parte degli agenti, in modo tale da differenziarne il comportamento nelle due situazioni. L'azione da parte degli agenti viene inoltre calibrata da un modello di panico progettato appositamente per l'evacuazione di edifici sottoposti a sisma e che permette di simulare le variazioni delle capacità decisionali che l'ansia può causare agli esseri umani. Questo modello tiene conto della eventuale visibilit à di un'uscita d'emergenza, della densità di agenti nella zona e dei tempi di evacuazione, il cui valore iniziale viene determinato dall'analisi strutturale ed i dati di ansia riportati da Takahashi (2010) [54], i quali documentano lo stato di ansia delle persone soggette al test sul panico e dalle capacitá motorie su tavola vibrante.

I modelli sopra citati sono stati realizzati tramite la scrittura di un software mediante il linguaggio di programmazione C++11 e l'integrazione di un framework ABM e Parallel Computing chiamato Repast HPC, progetto opensource realizzato dall'Argonne National Laboratory. Il movimento degli agenti è stato invece implementato applicando un algoritmo di Intelligenza Artificiale (Lee's Algorithm, 1961 [32]). I risultati riportati nei Capitoli 7 e 8, dimostrano come la modellazione del comportamento umano e del danno strutturale aumentino notevolmente la precisione dei risultati finali ottenuti dal software.

Negli ultimi anni, gli accelerometri di tipo Micro Electro-Mechanical Systems (MEMS) hanno dimostrato di offrire una applicazione valida in ingegneria civile per il monitoraggio strutturale (SHM). Sulla base dei promettenti risultati preliminari ottenuti in questa attività di ricerca, viene poi discussa una loro possibile applicazione per l'identificazione di danni strutturali su scala reale, per dare prova della loro rilevanza tramite calcoli comparativi verso i risultati dimostrati nella letteratura passata. Essere in grado di limitare l'effetto di disastri, limitando i danni e monitorando continuamente la condizione strutturale degli edifici, porta inoltre il modello ABM proposto a mantenere l'applicazione di danni strutturali al livelli minimi, permettendo di ottenere quasi sempre evacuazioni ottimali. A tal proposito, come descritto a partire dal capitolo 9, la ricerca si è quindi concentrata sullo studio di una tecnica di monitoraggio dello stato di rischio strutturale degli edifici tramite l'utilizzo di sensori dotati di accelerometro digitale ad altissima precisione, attraverso il quale è possibile ottenere il periodo naturale della struttura in condizioni stazionarie e poter così valutare la presenza di danni confrontando i dati raccolti prima e dopo un terremoto, ottenendo così non solo un rapido sistema di allarme, ma anche una tecnica di stima continua del rischio. Questa parte di ricerca è stata condotta in collaborazione con Safehub Inc., società con sede a San Francisco e testata sul territorio della California, negli Stati Uniti d'America.

Chapter 2

Introduction and Motivations

Agent-based modeling (ABM) is a modern and powerful tool for testing the collective effects of individual actions. One of the most important ABM applications in Civil Engineering is the simulation of crowd evacuation for buildings.

Most of the examples in literature, described in Chapter 3, focus on increasing the affidability of these simulations by refining human behavior models without taking into consideration most of the alterations that fires, explosions or earthquakes can create to structural and non-structural components.

This study links together structural analyses, damage scenarios (including non structural components), panic models and ABM simulations to simulate the evacuation of a building after an earthquake. The presented case study is an ideal three-story building set in Oakland (CA) and made of steel with base isolation (Friction Pendulum bearings). Structural analyses were performed on OpenSees software by researchers of the Pacific Earthquake Engineering Research Center (PEER, U.C. Berkeley).

Furthermore, this research includes the development of a human behavior model and a panic model, both oriented in earthquake evacuation simulations. Models take into account the most important aspects of human behavior during emergencies, including the variations that anxiety can bring to the decisional capacity. A first model, described in Chapter 4, has been created according to a simplified version of the Extended Belief, Desires and Intentions framework and it is based on a survey that has been run both in Italy and in the U.S.A.. The questionnaire design, described in Chapter 6, involved social desirability bias mitigation tools, according to Ajzen's "Theory of Planned Behavior" (1991) [1]. The model takes into account the most important actions that an agent can perform during the evacuation: leader-follower behavior of an agent respect to the group formation, helping a seriously or not seriously injured person and the research of missing individuals. Through this model, agents are evaluated taking into an account their feelings: the sight of an emergency exit, the injury status and if the person is alone or with his/her family or friends. The panic model simulates the anxiety effects in the human decision capacity and it has been specifically designed for building evacuation in case of earthquakes including three parameters: sight of an emergency exit, evacuation time and density of occupants. Its starting value has been calibrated by using the shaking table results of Takahashi (2010) [54] in order to find a correlation between structural analyses results and people's anxiety levels that were analyzed through a complete campaign of shaking table tests.

The models that have been described above are designed for each agent: this work employs an Artificial Intelligence model described in Chapter 5 to simulate crowd behavior. This model considers the agents' interaction with other agents, obstacles and speeds, according to their injury level and decisional states.

Chapter 7 describes how structural analysis results were implemented on *PACT* (Performance Assessment Calculation Tool, by FEMA) in order to create the damage scenarios in terms of percentage of injured people and obstacles created by collapsed components.

Evacuation simulations involved the use of *Repast HPC* software tool (by Argonne National Laboratory) and they go beyond the traditional evacuation simulations by using parallel computing to increase reliability and expansion of the models. As reported in the cumulative charts in Chapters 7 and 8, the use of damage scenarios and two refined human behavior and panic models permitted to define at best an escape path for each agent, bringing the results closer to reality.

In recent years, Micro Electro-Mechanical Systems (MEMS) accelerometers have proven to offer a suitable solution for Structural Health Monitoring (SHM) in civil engineering applications. Based on the well promising preliminary outcomes of this research, their possible application for the dynamic identification of existing, full-scale structural damages is then discussed, giving evidence of their potential via comparative calculations towards past literature results. Being able to limit the occurrence of disasters by preventing damage and continuously monitor buildings, leads the proposed ABM model to simplify its application by limiting the implications of structural damage, leading almost always to optimal evacuations levels. In this regard, as described from Chapter 9, this research activity focused on the study of a building monitoring technique that uses sensors equipped with a very high precision digital accelerometer, through which it is possible to compute the natural period of the structure in stationary conditions, thus estimating presence of damage and therefore allowing to compare the data collected from a building before and after an earthquake, obtaining not only an early warning system, but also a risk assessment technique. This part of research was carried out in collaboration with Safehub Inc., a San Francisco based company.

Chapter 3

State of the art

This chapter aims to give an overview of the current state of the art this research refers to. The first paragraphs describe the history of human Agent-Based Modeling, then a lot of modern civil engineering applications are described together with a description of the possible methodologies that researchers used in the past or they are using nowadays to describe the human behavior. Finally, the last paragraphs will focus on the current solutions and applications of sensor-based studies, for this research to improve this technology and provide strength for ABM models to be used in ideal conditions.

3.1 ABM Introduction

Agent-based modeling (ABM) is a methodology for testing the collective effects of individual actions. In general, ABM allows the examination of macro-level effects from micro-level behavior. Science requires the understanding of how an observed characteristic of a system (e.g. a solid) can be accounted for by its components (e.g. molecules). ABM is used in a vast range of fields like biology, business problems, ecology, social and earth science, network theory, technology and also civil engineering. In ABM, components and environment in which they exist are both modeled, in order to observe if the overall system behavior of the model matches the target (or subject) system behavior. The benefits of using ABM over other modeling techniques can be described in three statements, as of Bonabeu (2002) [6]:

- ABM captures emergent phenomena that are the result of the interaction among the agents.
- ABM provides a natural description of a system: In many cases, ABM is most natural for describing and simulating a system composed of "behavioral"

entities. Whether one is attempting to describe a traffic jam, the stock market, voters, or how an organization works, ABM makes the model seem closer to reality.

- ABM is flexible: this flexibility can be observed along multiple dimensions. For example, it is easy to add more agents to an agent-based model. ABM also provides a natural framework for tuning the complexity of agents: behavior, degree of rationality, ability to learn and evolve, and rules of interactions. Another dimension of flexibility is the ability to change levels of aggregation: one can easily play with aggregate agents, groups or single agents, using different levels of description in every given model.

In agent-based modeling, a system is modeled as a collection of autonomous decision-making entities called *agents*. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. An agent can interact with others, it is flexible and has the ability to learn from the past and to adapt his behaviors based on the experiences. A definition of *agent* may represent individuals, groups, companies and so on. The models of their behavior and the reciprocal interactions are formalized by equations, but it is possible to consider individual variations in the behavioral rules and random influences. Furthermore, ABM can be combined with other simulation methods used in natural and engineering sciences, including statistical physics, biology, cybernetics and, as proposed by this study, sensors based models.

3.2 Brief history

One of the earliest made agent-based model was the segregation model by Schelling (1969) [48] from Harvard University, which was discussed in Schelling (1971) [47] "Dynamic Models of Segregation". Even if he did not planned the use of computers, his models embodied the basic ABM concepts of autonomous agents interacting in a shared environment that gives singular and aggregated results.

Modern ABM has been created by Axelrod (1981) [3] with his revolutionary simulations of cooperative behavior. On this topic, in the appendix of Axelrod (2006) [4],the four research goals on this field are described as following:

- Empirical: "Why have large-scale regularities evolved and persisted, even when there is little top-down control?";
- Normative understanding: "How can agent-based models be used as laboratories for the discovery of good designs?";

- Heuristic: "How can greater insight be attained about the fundamental causal mechanisms in social systems?";
- Methodological advancement: "How can we best provide ABM researchers with the methods and tools they need to undertake the rigorous study of social systems and to examine the compatibility of experimentally-generated theories with real-world data?".

In the '90s, with the appearance of frameworks like StarLogo, Swarm, NetLogo, RePast, AnyLogic and GAMA, ABM started to being applied in several fields, beginning with social sciences. ABM began to focus on issues like designing effective teams, understanding the communication required for organizational effectiveness and the behavior of social networks. More recently, Sun (2006) [53] developed methods for basing agent-based simulation on models of human cognition, known as "cognitive social simulation". Bonabeu (2002) [6] instead described very well the potential of modern ABM simulations. Many researchers at the University of California, Los Angeles (UCLA), have also given significant contributions to the organizational behavior and decision-making: since 2001, UCLA arranges annual conferences that has become one of the major gathering points for practitioners in this field.

3.3 ABM applications in Civil Engineering

Nowadays, ABM simulations are performed in several fields of civil engineering: from the thermic assessment of a building to the simulation of terrorist attacks. For example, one of the most important studies in the field of energy assessment in a building has been done by Lee (2013) [35]. In this work he simulated human interaction with the energy performances of a building: researchers mixed the EnergyPlus software with an ABM for a single agent written with Matlab, using few equations for modeling behaviors and giving priorities to the thermal comfort.

However, the aim of this work is to simulate the evacuation of infrastructures and buildings during emergencies, one of the most important fields in which ABMs have been developed in the recent years. These helps designers and legislators to demonstrate if a designed building is safe and if the occupants will be able to evacuate during an emergency. Evacuation simulations can be done on site: they allow researchers to get a huge amount of reliable data, but in many cases these simulations can not be performed in all the infrastructures. For instance, if an administration wants to run a simulation for an airport terminal, the economic losses caused by the huge cost of the simulation or the inconveniences caused to passengers and flights might be too high, as Tsai (2009) underlined [59]. Therefore, today's best way to simulate an evacuation is to run an agent-based model on a computer.

Gwynne (1999) [25] studied crowd behavior during fire emergencies and divided ABM civil engineering applications in three categories (optimization, simulation and risk assessment models):

- Optimization models are created in order to optimize the position of all the emergency furnitures. Therefore in these models the human behavior is not well defined: evacuees are considered like a uniform flow.

- Simulation models: they are created in order to take into consideration all the aspects of the human behavior during an evacuation, including feelings and actions that are not strictly related to the evacuation process. These models allow designers to simulate, for example, how people use the designed emergency exits, the crowd formation and the evacuation time at a specific damage or hazard scenario.

- Risk assessment models attempt to identify hazards associated with evacuation resulting from a fire or related incident and attempt to quantify risk. By performing many repeated runs, statistically significant variations associated with changes to the compartment designs or fire protection measures can be assessed.

According to Tsai (2009) [58], crowd simulations can be classified as "macro-oriented" or "micro-oriented". Micro-scale simulations, in civil applications, consists on set the agent as a single human brain, with models that represent its behavior. Macro-scale simulations are the ones who make agents to interact with the environment.

The following examples describe the massive use of ABM simulations for town evacuations: here agents are families evacuating cities by specific means of transportation.

- Raney (2003) [45] created an ABM simulation for the Swiss Travel combining micro and macro scale simulations. From a micro-scale point of view, they considered an *agent* each traveler having his own behavior: agents are intelligent and they have strategic and long-term goals. The macro-scale point of view is their approximation to particles in a fluid dynamics flow. By combining the two simulations, a complex system can be represented.

The last example introduced an important field in which crowd simulations are used: in recent years, transport planners have been using ABM simulations for designing evacuation plans in urban environments. ABM is considered during transportation studies by using modern softwares (e.g. TRANSIMS) that are considered a new development of transportation.

- Chen (2008) [12] applied ABM in the simulation of an evacuation of an entire town. This study uses an agent-based technique to model traffic flows at the level of individual vehicles and investigates the collective behaviors of evacuating vehicles.

- Yin (2014) [64] created an agent-based travel demand model system for hurricane evacuation simulation, which is capable of generating comprehensive household activity-travel plans. The system implements econometric and statistical models that represent travel and decision-making behavior throughout the evacuation process.

- Zia (2013) [66] created a big simulation of movements in a medium size European city. He created a Cellular Automata (CA) grid from a raster image of a city (CA definition is given in the following paragraphs). Then they modeled the city and human behavior in Repast HPC and they printed the results on raster images that were scaled to the resolution of the CA grid. This work is so important because this thesis refers to it in many aspects, in particular in the software that is used, in the definition of some human characteristics and in the outputs definitions.

- Perkins (2015) [43] developed an ABM simulation for creating a model for reducing the dwell time in train stations. One of the key parameters (or optimization factors) was the width and number of doors in a train.

The complexity of cities evacuation models is caused by the huge dimensions, so researchers needs to parallelize calculations in order to fasten simulation times and increase reliability. This research aims to do the same for building evacuation: some cities models are added into building models. In these simulations, agents are individuals (each human being, dynamic agents) and the environment. The following examples are the current works that literature presents about ABM simulations of buildings.

- Tang (2008) [55] created an agent-based simulation model for a building in case of fire evacuation. They used a fire dynamics simulator (FDS) based on the computational fluid dynamics and a geographic information system software (GIS) with an ABM application to model the occupants response. Their case study demonstrates that the evacuation model effectively simulates the coexistence and interactions of the major factors including occupants, building geometry, and fire disaster during the evacuation.

- Dai (2013) [15] used an ABM to simulate an emergent evacuation in the Georgia Dome (Atlanta, GA), in order to evaluate the clearance time of evacuation of the stadium and the crowding areas. The behavior of evacuees included the maintenance of personal spaces, following groups and any behavior of a group during an evacuation. The building design factor that was also examined is the size and the location of bottlenecks.

- Tsai (2009) [59] simulated the evacuation due to multiple improvised explosive devices (IEDs) explosions at the Los Angeles International Airport (LAX). An important starting point of that simulation was that in airports there are not only business people (like in a train station during a work day), but also a huge number of families. Households present a completely different model of human behavior, as they no longer follow the often assumed "self preservation" edict and often seek to ensure the safety of family members first.

3.3.1 Specific models for Building Fires

In lieu of data and theory, evacuation models (and users) make assumptions and simplifications about occupant behavior, which can inappropriately characterize the time it actually takes to evacuate a building. When assumptions lead to too optimistic or too conservative evacuation estimates, buildings and emergency measures can be designed with either insufficient or unnecessary (and costly) egress routes and fire protection/notification systems. There is a lot of history in conceptual models of human behaviour in fire. Research into disasters, based on methods from the social sciences, has led to the development of theories and perspectives that can be related to building fire emergencies. Previous models are based upon a theoretical framework of individual decision-making and response to emergencies [51] and even by factoring the influence of actions that include information seeking, milling, preparing for evacuation, and informing others. A large body of behavioural research has shown that occupants, either individually or within groups, engage in a decision-making process before evacuating. Occupants perceive certain cues, interpret the situation, establish the risk to them based on those cues combined with prior knowledge and experience, and then make a decision as to what to do (i.e., select an action) based on these interpretations. In more advanced simulation models, a new performance element is considered, the Behavioural Itineraries. The user can address evacuee delays during evacuee movement by assigning behavioural itineraries to evacuees or groups of evacuees. Behavioural itineraries are tasks performed during the pre-evacuation or movement phases of an evacuation, and are assigned usually to the individual or group. The behavioural itinerary requires the definition of the locations visited during the evacuation and the time spent at these locations. The itinerary then implicitly represents evacuee movement and the associated delays that are not directly associated with movement to a place of safety. By analyzing such models, it becomes clear how understanding and representing evacuee behaviour, as a model user and a model developer, is a difficult and complicated task. This task is made more difficult by the tendency to oversimplify and focus on the physical aspects of an evacuation, rather than the psychological and the sociological aspects. It is hoped that with the research proposed by this work, a wider array of evacuee behaviours will be considered in the modelling process to fill the gap.

3.4 Human Behavior Models during evacuations

The human behavior is a complex mechanism influenced by culture, attitudes, emotions, values, ages, perception and many other aspects. During an evacuation simulation, the human behavior must be divided in three simpler components:

- The state, which includes the role performed in the evacuation and the age of the individuals. These characteristics involve different static and basic behavior. Different projects have different quantities and percentages of people that are involved in different roles (e. g. a man that in a specific emergency is alone, but in another context he can be with his son).
- Crowd Behavior. Individuals in a crowd behave in different ways: they have been widely studied and classified. These behaviors are mostly influenced by kinship, aggregation phenomena or collision events.
- Individual behavior, which considers the emotional aspects of a person. This is the most variable and unpredictable aspect.

The following paragraphs explain the state of the art of frameworks for Individual and Crowd behavior models.

3.5 Crowd behavior models

Human crowd is a complex but fascinating social phenomenon in nature. In some situations, a crowd of people shows well-organized structure and demonstrates tremendous constructive power, but in other situations, people in a crowd seem to abandon their social norms and become selfish. That is why crowd models are so complex. Zheng (2009) [65] has given a detailed description of all the possible models for crowd behavior simulation.

3.5.1 Cellular Automata approach

The first Cellular Automata study was made by Von Neumann (2010) [61]: the crowd is represented as a collection of homogenous individuals who react to the events and environment accordingly to some simple rules (like a fluid in a duct). In CA-based models, the environment is divided into a grid consisting of cells. At each time step, each cell is subject to a new state based upon its current state and the neighboring cells (Shanthi, 2012 [49]).

3.5.2 Lattice Gases approach

It is a special case of Cellular Automata, and popularized in the 1980s. This model is often used to study the features of a pedestrians crowd by means of probability and statistics. In lattice gas models, each pedestrian is considered as an active part of the grid. Lattice gas models have been applied to study the characteristics of pedestrian flow in different small building structures, like the crowd flow going outside a hall with bottlenecks formations and T-shaped channels.

3.5.3 Social Forces approach

In 1995, Helbing and Molnar proposed a social force model for pedestrian motion. The total effect a person is subjected to, has been described through mathematical expressions that include the effects of pedestrian desire, repulsive feelings of pedestrians and environment borders or attractive effects (Helbing, 2000 [27]). Quinn (2010)[44], showed how the model takes into an account wall and obstacles avoidance, because of a better simulation grid that can implement an obstacles map. In recent years, social forces models have attracted great attention from some researchers and have been further developed to study crowd evacuation. In particular, they have been combined with other models like Lattice Gases approach.

3.5.4 Fluid-dynamic models

Pedestrian crowds have been described with fluid-like properties over the last decades. Bradley (1993) [7] has hypothesized that the Navier-Stokes equations governing fluid motion could be used to describe similar situations for very high densities crowds: the footprints of pedestrians in snow look similar to streamlines of fluids or, again, the streams of pedestrians through standing crowds are analogous to riverbeds. Fluid-dynamic models describe how density and velocity change in time with the use of partial differential equations. The problem of these models is that panic effects are difficult to be described. Furthermore, Colombo (2005) [14] presented a continuous model for pedestrian flow to describe typical features of this kind of flow such as some effects of panic. In particular, this model describes the possible overcompressions in a crowd and the fall in the outflow through a door of a panicking crowd jam. They considered the situation where a group of people needs to leave a corridor through a door. If the maximal outflow allowed by the door is low, then the transition to panic in the crowd approaching a door may likely cause a dramatic reduction in the actual outflow, decreasing it even more.

3.5.5 Agent-Based Models

ABMs are computational models that build social structures with a "bottom-up" approach, by simulating individuals using virtual agents, and creating emergent organizations out of the operation of rules that govern interactions among agents. Panic behavior is an emergent phenomenon that results from relatively complex individual-level behavior and interactions among individuals. ABM seems ideally suited to provide valuable insights into the mechanisms and preconditions for panic and jamming by incoordination. In the last few years, the ABM technique has been used to study crowd evacuation in various situations. ABMs are generally more computationally expensive than cellular automata, lattice gas, social forces or fluid-dynamic models, also because they implement a lot of aspects of all the other methods. Their ability to allow each pedestrian to have an unique behavior makes ABMs the favorite models for modeling heterogeneous humans.

3.5.6 Game approach

The interactive situation, specified by the set of participants, the possible course of action of each participant, and the set of all possible utility payoffs, is called a "game". In a game, the evacuees assess all of the available options and select the alternative that maximizes their utility. Each evacuee's payoff depends on the actions chosen by all evacuees. This method is simple and it can be adopted for little models. When only one exit is available, the competitive behavior of the pedestrians in emergency egress could be interpreted in a game theoretical way.

The model of this thesis requests a huge variety of behaviors, in order to simulate different scenarios and people attitudes during emergencies in the same work. Agent-Based Modeling is the most powerful tool available in literature for the goal that the thesis aims to reach.
Agent-Based models can be divided into two categories:

- Deterministic models, which tend to be simpler to use, but do not take into account the possible variations of human behavior. If several simulations of the same model are run with the same inputs, the results will be exactly the same

- Stochastic Models, which can produce different outputs because of their stochastic definition. They are more complex than the previous ones and they need to be run several times in order to have, on average, more reliable results than deterministic models.

3.6 Individual Behavior models

In the following paragraphs there is reported a description of the most used individual behavioral models for ABM: SOAR, Act-R and BDI, that is the selected one for this research.

3.6.1 State, Operator And Results

SOAR (State, Operator And Results) has been developed in 1983. It is based on the syllogisms theory: it uses an associative mechanism to identify knowledge relevant to current problems and to bring it to bear potential solutions. A pattern matcher compares a representation of the current context to the activation conditions for each element in the system's knowledge base. In Soar, every decision is made through the combination of current interpretation of sensory data, the contents of working memory created by prior problem solving, and any relevant knowledge retrieved from long-term memory. The problem solving process in Soar is implemented as a search through a problem space (consisting of different possible states) that allows to solve the problem, nay to reach the goal state.

3.6.2 Act-R

Act-R is a hybrid cognitive architecture (Anderson, 2001 [2]). It is based on psychology, which is used to construct assumptions about human cognition. These are based on numerous facts derived from psychology experiments. The human behavior is discretized thanks to two sub-modules: memory and perceptual-motor, which consider the interaction between a human and real world. Mind processes can be summarized by mathematical equations. Firstly an utility equation estimates the relative cost and benefit associated to each production (knowledge about how we do things) thereafter, the execution (action performed) is the production with the highest utility. The retrieval equations are used when a fact can be retrieved from declarative memory, which considers the context and the history of usage of that fact. Act-R has its own programming language and it has been used successfully to create models in domains such as learning and memory, problem solving, decision making, cognitive development and so on.

3.6.3 BDI - Belief, Desire, Intention

The BDI paradigm was invented by Bratman (1987) [8] and it describes human reasoning and actions in everyday life using programming language and it has been applied successfully in many softwares. Because of this straight forward representation, the BDI paradigm can easily map extracted human knowledge into its framework. This characteristic enables a BDI paradigm-based system to imitate the human reasoning and decision-making process, and also makes the system easy to be understood by an actual human being (Lee, 2009 [33]). The BDI paradigm provides a "strong" notion of agency: agents are viewed as having certain mental attitudes (Beliefs, Desires and Intentions, which represent, respectively, their informational, motivational and deliberative states). In BDI the architecture of an agent can be completely specified by the events that it can perceive, the actions it may perform, the beliefs it may hold, the goals it may adopt and the plans that give rise to its intentions. In Bratman's theory (1987) [8], an agent divides its thinking time between deliberating about its intentions, and planning how to achieve them. BDI identifies three types of deliberation:

- Goal deliberation, which is the process of generating a consistent set of goals, perhaps by selection from a set of desires;
- Intention deliberation, which means choosing a goal (or goals) that the agent will act upon (and so will become an intention);
- Plan deliberation, which means constructing a plan, or selecting one from a plan library, that will further be one or more of the agent's intentions.

BDI, Soar and Act-R concentrate on the actual brain mechanisms during information processing, including tasks such as reasoning, planning, problem-solving, and learning. Consequently, these models become complex and difficult to be understood (Lee, 2009 [33]). Therefore, BDI is the most powerful and easy way to implement a model because it imitates easily the human reasoning and decision-making processes.

3.7 HPC in ABM

Multi-Agent Systems (MAS) are seen as a promising technology to face the current requirements of large-scale distributed and complex systems [36]. ABM is a category of MAS. The application of MAS to such large scale systems, characterized by millions of distributed nodes, imposes special demanding requirements in terms of fast computation. High Performance Computing (HPC) technology is a reliable solution for this purpose.

3.7.1 HPC definition

HPC systems are based on hardware architectures with a large number of processors: these cores work in parallel, so that they can execute multiple instructions simultaneously. The reason of this architecture is to save a huge amount of time in calculations and to improve precision. Therefore, besides the compute power, the major challenges with the high end field of applications and economical resources usage there are an efficient communication and data locality: the most important requirements for a well designed HPC simulation are the intelligent design of instruction sequences and memory usage, in order to avoid bottlenecks during their flow.

3.7.2 HPC application in ABM

Parallelizing MAS applications means deploying and running multiple intelligent agents on several computational resources nodes. However, the distribution of multi-agent system execution is a complex task, due to the technical particularities and to the intensive communication among agents and environment. Additionally, individual agents needs to modify the environment itself during their decision-making processes which, in terms of parallelization, are translated to the need to share several layers of environmental data and agents, which is a complex process. HPC technologies help researchers to develop the reliability of the human behavior simulation, giving the sufficient computational power for running, for example, better crowd models instead of a traditional Cellular Automata approach:

- Quinn (2010) [44] has modeled Terminal 1 at O'Hare International Airport in Chicago. They designed the simulation as a C program with calls to the Message Passing Interface (MPI) library (MPI is the most popular message-passing library standard for parallel programming). Passengers have been roughly described with the Social Forces Model (a model for only pedestrian movement).

- An important milestone in crowd simulations is reported by [19]. Authors explained how they simulated a crowd of more than a million people during a marathon in Istanbul: in the model they included all the objects of urban architecture, involving ABM (with the characterization of runners and public) and the parallelization of computational processes. The simulation has been written in C++ and ran on NVIDIA CUDA GPUs. The success of that simulation consisted also in a 3D representation of the results.

Moreover, an HPC tool has added to many traditional ABM frameworks in recent years: two examples are NetLogo by Thiele (2013) [56], which can be parallelized by R through a toolkit, and Repast, which has seen the new edition for HPC simulation (released in May 2015). An important application of these software tools is the model that has been made by Zia (2013) [66]: it is described in paragraph 2.3 and it used Repast HPC.

3.8 Sensors-based studies

Smart sensor networks produce pervasive structural health monitoring (SHM) information. With various embedded sensors, smartphones have emerged to innovate SHM by empowering citizens to serve as sensors. By default, smartphones meet the fundamental smart sensor criteria, thanks to the built-in processor, memory, wireless communication units and mobile operating system. SHM using smartphones, however, faces technical challenges due to citizen-induced uncertainties, undesired sensor-structure integration, and lack of control over the sensing platform. This study aims at extending the capabilities of smartphone-based SHM with a special focus on the lack of control over the sensor (i.e., the phone) positioning by citizens resulting in unknown sensor orientations. Using smartphone gyroscope, accelerometer, and magnetometer; instantaneous sensor orientation can be obtained with respect to gravitational and magnetic north directions. Advances in sensor technology and computational power, as well as extensive research in system identification, made structural health monitoring (SHM) one of the highlighted topics in mechanical, aerospace, and civil engineering (Doebling, 1998 [17]). As a result of rapid urbanization and industrialization, the infrastructure stock tremendously increased in developed cities. Aging infrastructure, natural disasters, and manmade hazards threatened structural integrity, serviceability, and occupant safety; necessitating implementation of SHM technologies to a broader extent (Stolz, 2010 [52]). Shifting from non-destructive evaluation to SHM, identification of structural characteristics gained a global, large-scale, and data-enriched perspective (Derriso, 2014 [16]). Gathering sensor data from multiple channels and processing data with advanced identification algorithms, structural models with uncertainties are validated, verified, or updated with monitoring data, and in this way, the actual dynamic behavior of structures is represented with a better accuracy. Advent of the Internet, wireless communications, and cloud technology gave rise to remote sensing, distributed sensor networks, and smart sensors in the last two decades. Due to practical and economic reasons, monitoring of civil infrastructure with temporary instrumentation became widely applicable compared with the sensor systems permanently embedded in structures. Integrating sensors with small-sized computing, data acquisition, and wireless data transfer units, smart sensor technology became a feasible choice for monitoring structural systems (Cimellaro, 2014 [41]).

3.9 Smartphones in SHM

Smartphone industry rose tremendously in the last decade. Basically, smartphones are equipped with computing hardware such as central processor unit, randomly accessible memory, and data storage components. They are capable of sending and receiving data wirelessly with the help of global system for mobile communications, internet, and bluetooth connection. What is more, thanks to the rapid advancements in microelectromechanical systems (MEMS) technology, smartphones are equipped with low-cost sensors such as accelerometer, gyroscope, and magnetometer which can measure device motion in six degrees of freedom (6DOF). To summarize, smartphones can compose a large SHM sensor network which has all the features of typical smart, heterogeneous, and mobile sensing platforms. Latest advances in data sciences imply that citizens and smart cities can benefit from crowd participants through multisensory mobile information. Innovative citizen engagement and crowd motivation methods are proposed and implemented through actual community examples (Bellavista, 2015 [5]). Using the advances in sensors and information technology, crowdsensing can become a powerful source for smart cities needs such as air quality assessment (Brienza, 2015 [9]) and environmental noise monitoring (Hu, 2015 [28]). Encouraged by the aforementioned advances, a citizen-engaged structural vibration measurement platform can be constructed with the help of multisensory smartphones. On the other hand, considering smartphone-based SHM as a participatory sensing problem, there might be a significant accuracy difference between conventional monitoring and crowdsourced results (Ozer, 2015 [40]).

3.10 Sensor system for building integrity monitoring

Nowadays, buildings and infrastructure are designed to sustain ordinary or extreme dynamic loads (such as wind, traffic, earthquakes, impacts, etc.). In most of the cases, simplified design methods and simulation techniques are conventionally used, to describe the mechanical features of different structural typologies. However, their actual structural behaviour (i.e., fundamental period, vibration shapes, etc.) is properly assessed for a limited number of cases only, i.e., for critical buildings and infrastructures whose integrity and serviceability is of high importance for public safety and civil protection. Only a few of these strategic constructional facilities are then equipped with continuous monitoring systems. Several research efforts have been devoted in the last decade to the development of reliable and cost-effective monitoring devices equipped with Micro Electro-Mechanical Systems (MEMS). Dynamic measurements of human body movements, for example, were carried out via MEMS accelerometers by Benevicius et al. (2013) [60]. Hand-arm and whole-body MEMS-based vibration records were critically discussed, aiming at investigating the reliability of MEMS techniques for biomedical applications. The so-called bioMEMS gave evidence of their potential for the medical field especially, in the last five years (Ciuti, 2015 [13]). At the same time, MEMS accelerometers proved to be efficient also for vibration monitoring in industrial machines and rotors (e.g. Chaudhury, 2015 [11], etc.). Since the 1990s, major efforts and well-promising results were reported in the literature from the application of MEMS accelerometers in the SHM of civil engineering facilities, as well as in the early-bird monitoring of seismological hazards. In the first case, MEMS systems have been efficiently used for the monitoring of strong-motion events in rigid structures, but positive efforts have been also achieved from continuous MEMS measurements of flexible structures (such as vehicular and pedestrian bridges), as deeply discussed in several research papers. The collected vibration data showed close agreement with the experimental measurements derived from commercial devices for SHM purposes. A list of additional positive MEMS applications for the SHM and dynamic identification of civil engineering constructions, including wireless options, can be found in the literature (see for example Kok (2003) [30] and Torfs (2013) [57]). A number of research projects aimed to assess the feasibility of MEMS applications in the form of seismological alarm systems can then be found in the literature. Dashti et al. (2012) [46], for example, explored the use of cellular phones as ground motion instruments, giving evidence of their accuracy as seismic monitoring devices via comparative shake table tests. Similar results are also reported in Kong (2016) [31], etc.

Chapter 4

Individual Behavior and Panic models

In an Agent-Based Model, the human behavior model constitutes the core. The constant increase of computational power of computers and supercomputers allow researchers to develop refined (and complex) models. Evacuation simulations, as stated in Chapter 3, involve particular and sub-conscious behaviors: BDI paradigm is the selected method for this purpose. The research involves a methodology that has been explained by Lee (2008) [34] and it has the aim to create reliable mathematical expressions for modeling human decision making during crowds. In fact, the proposed human behavior model has been used for simulating crowd evacuation behaviors under a terrorist bomb attack in Washington D.C. National Mall area. This research enhances BDI framework through the panic model described in Paragraph 3.6: it is based on agent's feelings and it is calibrated through a real human feeling databases.

4.1 Introduction

Human behavior during emergencies is a complex field that most of times is mythologized by films and the media: such views are almost always inaccurate.

Human behavior and panic effects could not only be the responsible of some hazards (like fires, industrial accidents or terrorist attacks), but also compromise the evacuation procedure. For example, evacuees on a double deck aircraft that are forced to escape from the upper level have an higher degree of anxiety at the moment when they need to jump into the slide, so they will take more time in their egress process (Jungermann, 2000 [29]).

Factors and behaviors changes depending on hazard, environment types and researchers must be aware of modeling human behavior with assumptions that are built on "myths".

First of all, the majority of people in disasters behave with responsibility and concern for their neighbors. There are always stories of self interest in all disasters, but although they tend to get the most publicity, they are far from representative. Disaster planning should take into account the fact that most people will think about the others during an emergency (Lindell, 2006 [38]).

Another common misconceptions is to consider evacuees having the same behavior when, in fact, there are many segments of population that differ in their hazard knowledge, family roles, and material resources. In particular, emergency managers must distinguish among the function of each person in the building or, in general, in the simulation environment itself, because these population segments differ in their willingness and ability to evacuate. This consideration demonstrates that a refined human behavior model should take into account most of these differences. Consequently, in emergencies simulations, a crowd behavior model is not sufficient.

The statements above are valid when panic is not present. In general, panic is rare in disasters, but it can be a common problem in closed spaces like buildings. Normal people react to danger by doing the best they can for themselves and those with them. They may even make mistakes from lack of knowledge or confusion, which may even cost their or other peoples lives. The circumstances under which panic is most likely to occur are when people do not have adequate information about what is happening, there is an immediate perceived threat of death, or people feel themselves to be trapped by means of escape route being blocked and when there is a lack of leadership and direction. In conclusion, panic models should be designed in order not to distort the whole human behavior model, but to let the person continue to keep his/her capacity to think and help.

It is possible to summarize all of those aspects in three characteristics. The following points also report choices that have been made during the research:

- State module: agents are "normal people" like visitors and workers, so rescuers are not taken into consideration (because the structure is not severely damaged);
- Individual behavior: the relationship among friends and family members, the altruism (is an agent will help an injured person) and the leader-follower behavior;
- Crowd behavior: the interaction among agents and in particular the definition of the path towards the exit.

This chapter describes the individual behavior model. Challenger et al. (2009) [10] studied the behavior of crowds in real evacuation processes. Their study shows that a frequent phenomenon during the evacuation is the so called leader-follower relationship: in this software, agent's decision of following another person is affected by a stochastic model, calibrated through a survey. In another publication, the same authors reported the evidence of relationships among family members also during evacuation simulations: this aspect is deeply described and simulated in this model. The last aspect being considered is the help offered to an injured person. The research take into an account the possibility of helping a not seriously injured individual (defined as a person with small wounds) and a seriously injured human being (defined as a person that is incapable of moving and has severe wounds).

4.2 Modern BDI Development

BDI is a model of human reasoning process, where its mental state is characterized by three components: beliefs, desires, and intentions. Rao (1998) [23] developed Bratman's definitions:

- Beliefs are information which human has about the circumstance, and may be incomplete or incorrect due to the nature of human's perception.
- Desires are the states of affairs which human would wish to be brought about.
- Intentions are desires which human has committed to achieve.

As shown in Figure 4.1, its explanation and the following paragraphs are mainly taken from the framework that was proposed by Lee (2008) [34] for human behavior simulation during evacuations by using an extended version of BDI.

It is one of the possible frameworks for the BDI implementation and its application is complex. Concepts, sub-models and equations have been adapted for the purpose of this research. BDI framework, for defining a plan (normal mode), follows the following instructions:

- Environmental conditions are caught by agent's sensors (eyes, ears etc.);
- In the Belief Module, the Perceptual Processor interprets the data that comes from the sensors and generates subjective beliefs (given the same environmental condition, beliefs of different individuals will be different depending on their cultural background as well as levels of experiences and knowledge);
- The Desire Module, based on the current Beliefs, generates Desires, that are goals that the agent wants to achieve;

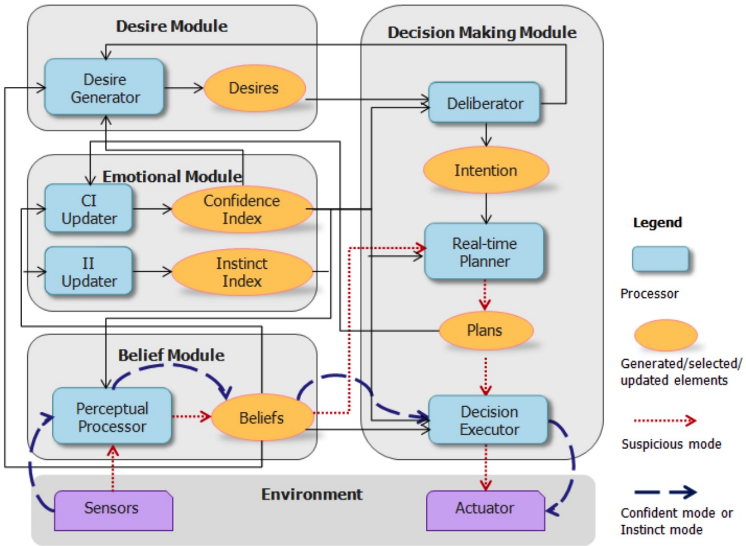


Figure 4.1: BDI framework

- In the Decision Making Module, the Deliberator generates an Intention (a short-term goal or one of multiple Desires) based on the Desire(s);
- In the Decision Making Module, the Real-time Planner generates a plan (i.e. a series of actions to be taken needed to achieve the intention) based on his current Beliefs (on his capability and environmental conditions);
- After a plan is developed, in the Decision Making Module the Decision Executor executes each action contained in the plan, which will affect the environment. If what is predicted during the planning stage is similar to what an individual faces during the execution stage, the Confidence Index (CI) in the Emotional Module increases, and he continues to execute actions until all the actions in the current plan are executed. The confidence index is a function of the deviation between what is predicted about the environment during the planning stage and the actual environment during the execution stage.

On the other hand, if there is a significant deviation between what is predicted vs. the reality, CI decreases. If the CI is below a threshold value, he develops a new plan (i.e. suspicious model) based on the current environmental condition and his beliefs (based on long-term memory) instead of completing the one previously developed. The Instinct Index Updater increases the Instinct Index in the event (e.g. decision making under time pressure such as evacuation from factory fire) for which the above mentioned reasoning process is not possible; in this case, the human being follows his instinct (i.e. long-term memory), which is part of Beliefs.

4.3 Belief Module definition

The belief module, in the software script, is definition of the agent's state. Thus, starting from its personal information (if it is alone or with family, if it is injured and its injury severity), the sensorial data will complete a list of variables that will define his status. In particular, sensorial data defines if he can see an emergency exit, an injured person a member of his family etc.. In Lee's framework, the Perceptual Processor is modeled with the Bayesian Belief Network (BBN). By using BBN it is possible to capture the probabilistic relationship together with historical information between variables by containing prior and conditional probabilities to infer the posterior probability through Bayes' theorem. This tool is useful but requires a significant amount of data. BBN for this research is instead replaced by the definition of interval of probability for each belief.

4.4 Decision Field Theory (DFT)

Decision field theory (DFT) is a model for the human Decision Making Module, which is based on psychological rather than economical principles. It provides a mathematical framework to represent the psychological preferences of humans on the given choices during their deliberation process. DFT can be used in order to realize a real-time planner sub-module in the Decision Making module of the proposed extended BDI for the normal mode agent. It provides a dynamic and probabilistic mathematical approach to simulate human deliberation process in making decision under uncertainty. It is dynamic because the time variable is a factor affecting the decisions as well as the changing of environment. In DFT, the human preferences can be described as reported by Equation 4.1.

$$P\,(t+h) = S \cdot P\,(t) + C \cdot M \cdot W\,(t+h) \tag{4.1}$$

Where:

- $\mathrm{P(t)} = [\mathrm{P_1(t)}, \mathrm{P_2(t)}, ..., \mathrm{P_n(t)}]$ is an n-element vector that represents the preference state, where Pi(t) is the strength of preference corresponding to option i at time t (h is the time step).
- S is the stability matrix, which represents the effect of the preference from the previous state (the memory effect) in the diagonal elements, and the effect of interactions among the options in the off-diagonal elements. For the stability of this linear system, the eigenvalues λ_i of S are assumed to be $\mid \lambda_i \mid < 1$.

- M is the value matrix (a m x n matrix, where n is the number of options, and m the number of attributes), which represents the subjective evaluations of a decision-maker for each option on each attribute. For example, given a information like smoke, fire, police or crowd, evacuators obtain their own subjective evaluations for each option (e.g. a path to a specific point) on each attribute (e.g. risk, evacuation time), which constitute the M matrix.
- W is the weight vector, (m elements vector), where m is the number of attributes. W(t) changes over time according to a stochastic process. It allocates the weights of attention corresponding to each column (attribute) of M. In the case that M is constituted with multiple states, each weight corresponds to the joint effect of the importance of an attribute and the probability of a state.
- The matrix C is the contrast matrix comparing the weighted evaluations of each option, MW(t). If one is evaluated independently, then C will be an identity matrix. In this case, the preference of each option may increase simultaneously. Alternately, the elements of the matrix C may be defined as c_{ii}=1 and c_{ij}=-1/(n-1) for i$\neq$j, where n is the number of options. The increase of preference for an option lowers the preference to alternative options.

Lee's method has been created in order to best fit the case of an evacuation of a big urban environment, in which people (or agents) are able to choose the exit path according to their feelings. In such model, the actions that can be performed are strongly connected together, because of the previous explanation: from a practical point of view, this model requires the use of artificial intelligence for solving the problems it was created for. The problem that this research has to solve does not require that type of artificial intelligence, because the paths that can be chosen by agents are in most of cases "single" (only one emergency exit is available). For such models, Lee suggests the researchers to "simplify" the methodology by taking into consideration only few aspects of the emergency, that can be strongly modeled through a survey, and to model them by using his matrices.

The assumption to not use artificial intelligence for searching an exit path is replaced with a smoother one, described in Chapter 7. In fact, this project involves the use of artificial intelligence to avoid all the obstacles after having calculated the shortest path towards an emergency exit.

Moreover, the original DFT model was created for modeling situations in which multiple choices are always possible. In reality, the evacuation of a building can lead the user to evaluate different scenarios, depending on gravity of the damages and its personal situation. In the model that is developed during this research, DFT matrices are designed in order to avoid correlation among possible actions, because they refer to all existing cases that can be presented to a specific typology of user: for example, there is no correlation among the possibility to help a relative, an injured person or to follow a group of people, if the agent can't see the emergency exit. This research employs a set of DFT matrices: a matrix for each typology of user.

Due to the difficulty to gain good precision for the M matrix calculation (for example, in a case with a 3x3 matrix, only 3 parameters could be calculated starting from 6 others chosen randomly), the research condensed the CxM matrices multiplication to a matrix called T.

$$P(t+h) = S \cdot P(t) + T \cdot W(t+h) \tag{4.2}$$

T matrix calculation should be done before the start of a simulation: because of this, the only values that can be used for the calculation of probability vectors P(t+h), P(t) and W(t+h) are the average values of W intervals, that are now called W_{avg}.

$$W_{avg} = S \cdot W_{avg} + T \cdot W_{avg} \tag{4.3}$$

Following Equation 4.3, T matrix can be easily calculated. The values of S components has been chosen according to Xi (2011) [63]. For a four dimensions case, S matrix is the following:

$$S = \begin{bmatrix} 0.9 & -0.01 & -0.01 & -0.01 \\ -0.01 & 0.9 & -0.01 & -0.01 \\ -0.01 & -0.01 & 0.9 & -0.01 \\ -0.01 & -0.01 & -0.01 & 0.9 \end{bmatrix} \tag{4.4}$$

For a three dimensions case, the S matrix becomes the following:

$$S = \begin{bmatrix} 0.9 & -0.01 & -0.01 \\ -0.01 & 0.9 & -0.01 \\ -0.01 & -0.01 & 0.9 \end{bmatrix} \tag{4.5}$$

Off-diagonal values are very small because each choice is independent from the others. At each step of the simulation, the probability is calculated through Equation 4.2, with a W(t+h) vector that is randomly defined everytime.
In the case of panic situations, the human brain does not work as previously described. History path, long-term and short-term memory does not influence impulsive decisions that a person can have under panic circumstances. For these situations, after defining the probability for each action through the Belief Module results, actions will be chosen randomly (according to the probability patterns just defined):

$$P(t+h) = W(t+h) \tag{4.6}$$

4.5 Individual Behavior: a questionnaire-based approach

In this work, eight types of agents are being defined:

- The agent is alone, it is not injured, it sees the emergency exit.
- The agent is alone, it is not injured, it does not see the emergency exit.
- The agent is alone, it is wounded but not seriously injured and it sees the emergency exit.
- The agent is alone, it is wounded but not seriously injured and it does not see the emergency exit.
- The agent is with his friends/his family, it is not injured and it sees the emergency exit.
- The agent is with his friends/his family, it is not injured and it does not see the emergency exit.
- The agent is with his friends/his family, it is wounded but not seriously injured and it sees the emergency exit.
- The agent is with his friends/his family, it is wounded but not seriously injured and it does not see the emergency exit.

Their behavior has been defined by the use of a survey explained in the following chapter. The questions that have been asked in the survey are:

- Will you help someone that is not seriously injured?
- Will you help someone that is seriously injured?
- You see the emergency exit, but you also see a group of people that is running in a different direction (a different direction than yours/the one for the emergency exit): would you follow them? (The question is written differently in case of emergency exit visibility or not).
- You are evacuating a building, but you do not see one or more friends or family members that were with you before: would you continue moving in your initial intended direction with your actual group? (This question is applied only to the last four categories).

According to the previous points, the first four types of agents are described through vectors in three dimensions and thus by 3x3 matrices. The last four typologies are described by four dimensions vectors and by 4x4 matrices instead.

4.6 Confidence Index

The panic model simulates the effects of anxiety in the decisional capacity. It can be expressed through the definition of a confidence index, defined as a function of deviation between what is predicted during a planning stage and the actual environment on the execution stage (Lee, 2008 [34]). If the confidence index is above a certain threshold (confident mode), the Decision Executor performs all the tasks in its plan, otherwise a re-planning is performed every time (suspicious mode). Lee's model for Confidence Index is the following:

$$CI_t = \alpha e^{-d_t} + (1 - \alpha)\, CI_{t-1} \tag{4.7}$$

where d_t is equal to:

$$d_t = \left(m^i_{risk} - m^{tresh}_{risk}\right) + \left(m^i_{time} - m^{tresh}_{time}\right) \tag{4.8}$$

where

- $d_t > 0$ denotes the deviation between what is predicted about the environment during the planning stage and the actual environment during the execution stage, where $\mathrm{m^i}_{\mathrm{risk}}$ is the evaluation of risk on the planned option i, $\mathrm{m^i}_{\mathrm{time}}$ is the evaluation of evacuation time on the planned option i and $\mathrm{m^{tresh}}_{\mathrm{risk}}$ and $\mathrm{m^{tresh}}_{\mathrm{time}}$ are the relative threshold values.

- $0 \leq \alpha \leq 1$ is a memory coefficient, that adjusts the effect of previous confidence to the current confidence, which varies depending on the individual human.

The confidence index is defined with values between 0 and 1. Lower values means very low confidence. Lee used four different levels in his examples, but the research (and the case study) does not have a sufficient amount of data for defining such high number (also because the definition of a single panic threshold value is sufficient to define human behavior in earthquake evacuation).

Lee's model can not be applied in this project because of the problems explained in the following list of pros and cons:

- It takes into account the evacuation time and the comparison of the risk of the safer path to the emergency exit with a risk threshold, but those last parameters require on-site experiments and further analyses with calibration software tools;

- As mentioned in the previous point, Lee's model is based on "path choice" methods, which are a branch of artificial intelligence. Those methods can be very useful in case of urban evacuation, but in a building simulation it can be meaningless, in particular when the building has paths that are already and uniquely given;

- No indications are given about the definition of a starting value of confidence index. In a building evacuation simulation, the evacuation time is more and more little respect to a neighbor evacuation, so the starting value of the confidence index is fundamental.

In conclusion, the model that should be used in this project must move from path and risk calculations to a simplified realistic method. However, Lee's CI model inspired the design of panic models because:

- It uses exponential functions like e^{-n} where n is a positive value: CI is comprised between 0 and 1, for high values of n the agent has a low CI (that means a lot of panic). The geometry of this function and Lee's considerations suggest to fix a "confidence threshold" at the value of 0.35;
- It takes into account the evacuation time, which is a fundamental parameter in panic feeling.

Li (2014) [37] considered a CI model in which confidence values are based on evacuation time, distance to the emergency exit and crowd density. This model use exponential functions, but the three components are not correlated to each other: the selected CI is the minimum value among the three results. This model was applied to a subway station simulation in case of a bomb attack. This model has some lacks. First of all, the starting value of the confidence index can not be defined and the model itself does not take into account a memory effect. Correlation among three components is also defined improperly: some of them can even assume a different amount of importance depending on the development.

The confidence index in this project is designed by following these guidelines instead:

- Use of exponential functions according to the previous models;
- Correlation between evacuation time, sight of the emergency exit and the density of people.

Equation 4.9 depicts the confidence index this research has developed:

$$CI_t = (1-\alpha)\left[\beta e^{-\gamma \frac{t}{\bar{t}}} + \left(\frac{1-\beta}{2}\right) e^{-d_t} + \left(\frac{1-\beta}{2}\right) e^{-\gamma \frac{\varrho}{\bar{\rho}}}\right] + \alpha CI_{t-1} \tag{4.9}$$

with β as a weight coefficient, that is equal to:

$$\beta = \frac{t}{\bar{t}} e^{-\gamma \frac{t}{\bar{t}}} \tag{4.10}$$

Where

- $0 \leq \alpha \leq 1$ is the "memory coefficient" and it is set equal to 0.6.
- $d_t > 0$ denotes the deviation between what is predicted about the environment during the planning stage and the actual environment during the execution stage and it must be higher than 0. It decreases or increases of a specific value if the agent is able to see/not to see the emergency exit. Its starting value and the increasing/decreasing values are calibrated through the average evacuation time.
- t is the actual value of time.
- $\bar{t}$ is the characteristic value of evacuation time without any obstacles due by damages: for this project $\bar{t}$ is defined as the time when 80% of evacuees have left the building.
- p is the density of people (agents) around the considered one.
- $\bar{p}$ is the threshold of people density: if p is higher than that value, the density component will lead the person in panic ($\bar{p}$ is set equal to 3 people/m^2)
- $CI_{t=0} \leq 1$, calibrated through shaking table test results (see Chapter 7).
- β is a weight coefficient. Its formulation is defined because this thesis assumes that the evacuation time does not influence the first steps of the evacuation.
- γ is a model coefficient and it is equal to 1.08, in order to have $e^{-\gamma}$ equal to 0.34, that is close to 0.33(the weight at $\bar{t}$) and 0.35(the panic limit). The reader should understand that these approximations goes further the reliability of the whole model.

Model calibration is done by calibrating the equation (including memory) to obtain a characteristic evacuation time component equal to 0.35 starting from 1 in the following hypothetical situation:

- No damages (no additional obstacles);
- No hazard;
- Starting CI value equal to 1.

For example, if $\bar{t}$ is 14 seconds, the offset value is 0.019. In this case it appear obvious that a simulation without damages and panic is required.

Chapter 5

Crowd behavior model and calibration procedures

This chapter describes assumptions and decisions that have been taken for the creation of a reliable crowd behavior model in the Agent-Based Modeling software. Paragraphs 5.1, 5.2 and 5.3 describes why important aspects like the human dimensions and their evacuation speed should be considered stochastic data. Agent-based models can not take into an account all those variations, thus some characteristics have been reduced to fixed values as described in the last paragraph.

5.1 Initial Conditions

In an Evacuation Agent-Based simulation it is necessary to define the following initial conditions:

- The starting position of the agents is decided stochastically.
- The quantity of people in the case study is defined by using real statistic data. Those data are available online as survey results or as requirements of national polices. The population assumptions are described in Chapter 7.3.3.

By following the described framework, the software was programmed to create a "zero scenario". Agents are also defined in their dimensions: Table 5.1 describes the general assumptions for humans diameter values, according to Smith (2008) [50].

Before starting the evacuation process, each person is subject to a response time, defined as time span between the moment when a person first hears an

Agent	Minimum 2.5 percentile	Maximum 97.5 percentile
Men	40	48
Women	35	45
Children	30	38
Average	35	44

Table 5.1: Dimensions of human width [cm] (Adapted from Smith (2008) [50])

alarm or feels the shaking and when he/she starts to move toward the exit of the building. This project does not consider this particular period of time.

This assumption is a strong limit in case of highly damaged structures, where there can be a lot of injured people who have long response times. In the case study of this work (described in Chapter 6) the structure is not severely damaged and a low percentage of people is injured, so the response time of agents can be superimposed on the shaking time.

5.2 Agent behavior assumptions

According to Vreugdenhil (2015) [62] a good agent-based model for building evacuation should consider the following crowd behavior aspects:

- Walls and obstacles avoidance;
- Trend toward the exit;
- Search of less crowded areas for moving easily;
- Attraction from the main stream.

In general, agents can be either alone or form a group. Families and groups of friends are special types that are constantly monitored starting from the beginning of a simulation. General behaviors of agents are described as follows:

- If an agent has no sight of a family member or a friend, he/she will probably looks for him;
- A not seriously injured person may need help or not;
- A not seriously injured person that does not need help can eventually help another person;

- An injured agent that has been rescued by another agent won't need further help in the future.

Evacuation time depends on the agent type:

- Non injured people: speed is like normal evacuation speed;
- Non seriously injured people: speed is like disabled speed;
- Seriously injured person: speed is zero until another agent helps him;

Directions are defined through a crowd behavior model. Values and variations of the speeds are reported in Table 5.2 (see Smith, 2008 [50]). Non seriously agents are considered as people with motion disabilities.

Agent	**Min.**	**Max.**	**Min. Stairs**	**Max. Stairs**
Men	1.10	1.60	0.85	1.05
Women	1.05	1.45	0.85	1.05
Injured	0.57	1.02		

Table 5.2: Evacuees' speed [m/s]. (Adapted from Smith, 2008 [50])

If an agent (or a part of a group of agents) decides to help an injured or seriously injured person, it can lose his own group. Then, during each step, the agent can decide if it is necessary to help this person or not. When he reaches the injured agent, he can resume his evacuation normally.

5.3 Crowd behavior

A crowd behavior model describes how an agent interacts with others. When agents are stuck in a bottleneck, they cannot move at the defined speed, but they are forced to wait their turn to pass the bottleneck situation.

5.3.1 Social Forces model

The Social Forces Model (Helbing, 2000 [27]) is a refined framework for the definition of crowd behavior on agent-based models. Like Newton's law, that model describes the components of the force that can move each agent:

$$m_i \frac{d\mathbf{v}_i\,(t+h)}{dt} = m_i \frac{\mathbf{v}_i^0\,(t+h)\,\mathbf{e}_i^0\,(t+h) - \mathbf{v}_i\,(t)}{\tau_i} + \sum_{j \neq i} \mathbf{f}_{ij} + \sum_{W} \mathbf{f}_{iW} \tag{5.1}$$

The change of position $r_i(t)$ is given by the velocity $\mathbf{v}_i(t) = d\mathbf{r}_i/d_i$. In this model, each pedestrian of mass m_i wants to move with a certain desired speed $v^0{}_i$ into a certain direction $e^0{}_i$ and therefore tends to correspondingly adapt his actual velocity v_i with a specific characteristic time τ_i. f_{ij} and f_{iW} are two "interaction forces" that are due to the interaction of an agent with, respectively, other human beings and obstacles.

Helbing's model is very refined, but it can not be implemented in the agent-based model of this project because of the following aspects:

- The environment is defined as a 2D matrix, which cells represent a 30x30 cm areas each;
- Repast HPC moves the agents according to space units instead of time units (one step is equal to one cell movement);
- Lee's algorithm (1961) [32] can simulate the artificial intelligence, so it will orient the agent according to the shortest path, moving him in the four cardinal directions.

5.3.2 Lee's algorithm

The adopted methodology is the Maze Routing Algorithm or Lee's Algorithm (1961) [32]. This method is based on the Breadth-First-Search (BFS) technique, that permits to find the shortest path between two points in a 2D matrix, a grid that represents the environment, including obstacles. Each agent can move in four directions: up, down, left, right.

Maze routing adopts a two-phase approach of filling followed by retracing. The filling phase works in the "wave propagation" manner: starting from the source cell S, the adjacent cells are progressively labeled one by one according to the distance of the "wavefront" from S until the target node T is reached. Once the target node T is reached, the shortest path is then retraced from T to S with decreasing labels during the retracing phase. This algorithm guarantees that the path between S and T will always be found and that it will be the shortest path to follow.

This research modified the algorithm in order to take into an account the presence of crowds: if an agent can not move in the further cell because of the presence of an agent, then the algorithm is repeated in order to compute a new path that allow to avoid it.

The algorithm has been implemented with C++11 code that uses Repast HPC.

5.4 Model Assumptions

5.4.1 Evacuation speed

In this project, a *step* is defined as agent movements equivalent to one cell. Thus, the following considerations can be done:

- The movement distance for a step is roughly 30 cm;
- This project assumes 0.25 seconds as temporal value for making a step, which means a frequency of 4 steps per second;
- The previous consideration means that the agents' speed is 1.2 m/s, which is close to Smith's considerations.

An important assumption should be done for injured agents: they can move only one step every two. Therefore, this assumption means an average speed of 0.6 m/s for the agent.

During each time step of the simulation, agents will absorb some important information for their decision capability, mainly made by sight or mental elaboration data. Thus, agent can recognize the presence of:

- the emergency exit;
- a member of his family;
- a group of people;
- an injured person;
- the injury gravity of that person.

During the simulation, at each time step, the software elaborates the sensorial data of the agent (sight data), then the following priority list will be respected involving also the data of border conditions that have been calculated in the previous time steps:

- Input of sensorial data;
- Calculation of the status;
- Calculation of possibilities of each action;
- Action definition (see the following Example).

At each step of this model, once the possibility of an action is determined through the model that has been described above, the software calculates if each action is performed: by using the internal clock, the processor defines a random value (from 0 to 1) and it compares it to the probability value P(t+h) (See Equation 4.2). If an action is not performed, the software will pass to the calculation of next one, otherwise the cycle is finished and the agent will act according to the defined action. It is possible to explain the process with the following example:

> *Example*
> *The agent is alone, he is not injured, he sees the emergency exit, he sees a seriously injured person and a group that is going to another direction.*
> *After the possibility values calculation, the software defines its probability values:*
>
> - *I help the not seriously injured person: 43.4% (Forced to 0%).*
> - *I help the seriously injured person: 35.2%.*
> - *I follow the group: 17.8%.*
>
> *The first calculation is performed on the first action: since the probability is 0%, the action will not be performed, so the calculation is repeated for the following case: if the random value is lower than the probability of that action, the agent will act helping the seriously injured person. If the response to that action is negative, the agent will repeat the process for the next action. If the response is again negative, the agent will continue to move according to his path.*

Chapter 6

Survey design

This chapter describes how the survey was created and distributed. The last sections reports the confirmation of good planning and the results that were implemented in the Agent-Based simulation.

6.1 A responder-oriented survey

The model implemented in this research is based upon survey results. Errors in the surveying activity may cause a terrible increase of biases, so the questionnaire has been created by involving modern theories for permitting the sample to be "caught" in each situation. The result of a well planed questionnaire is considered a model with strong mitigation of biases (social desirability bias in particular). The construction of a questionnaire has been based on similar research surveys and on Ajzen's Theory of Planned Behavior (TPB) (1991) [1].

6.1.1 Social desirability bias

When samples are responding a survey, they tend to distort their answers in order to explain how a "nice" person should behave in a specific situation. People tends to present themselves in the best possible light (Fisher, 1993 [22]). This phenomenon leads to a disruptive error in social sciences models: it is called the "social desirability bias". This bias in sometimes avoided by using indirect questioning, but in the case of evacuation scenarios it can lead to other types of biases. The most important problem in this field is the answer to the question "would you help an injured person?": if indirect questions are not applicable, one of the best ways to avoid (or mitigate) social desirability bias is to try to give the sample a real feeling about the emergency environment (images and videos), to give the sample multiple choices of answers and to create an algorithm for their management. The questionnaire has been created with 1 to 5 multiple choice questions: *"Yes", "Probably yes", "I don't know", "Maybe no"* and *"No"*.

Each of those answers are explained with a brief phrase, in order to allow the responder to think about the emergency situation. The responder is free to answer with one of the answers above, but the surveyor is able to modify how the answer is applied in the specific context. This research has interpreted the answer to the questions "will you help a seriously/not seriously injured person?" in the following way: the possibility to help a person is chosen randomly among the percentage of people who answered "Yes" and the total number of people who replied "Yes" and "Maybe yes". For the other actions, the possibility is chosen between the sum of "Yes" and "Maybe yes" and the sum of "Yes", "Maybe yes" and "I don't know" responses.

6.1.2 The implementation of TPB

The core of Ajzen's theory (1991) [1] is the individual's intention to perform a given behavior: intentions are assumed to capture motivational factors that influence behavior. An important postulate of his theory is that "*behavior is a function of salient information, or beliefs, relevant to the behavior*". People can perceive a huge number of perceptions simultaneously, but the total number that are instantaneously considered is very low. Thus, when modeling the human behavior, only salient perceptions should be considered. That is why a small number of questions have been asked to the responders. A "Behavioral Intention" can find its expression in behavior only if the behavior in question is under volitional control. Moreover, the performance of this behavior is not only influenced by the will (motivational factors), but also by other parameters such as skills and environmental conditions. These factors are defined as "actual behavioral control". This parameter is strongly influenced by perceptions, in fact Ajzen redefines it as "Perceived Behavioral Control". Each individual perceives in a different way, so this parameter is personal and for each person it changes across situations and actions. The final decision, that Ajzen calls "Behavioral Achievement", is pursued through the Perceived Behavioral Control and the Behavioral Intention. Perceived Behavioral Control strongly influences the decision taken in this research to divide the survey in 8 situations, in which the sample is invited to think about different statuses: the environmental conditions that are presented him will indeed influence its answers. In his study, Ajzen continues to remark the joint function of Behavioral Intentions and Perceived Behavioral Control for the performance of the action. This means that, to achieve a correct prediction of the behavior, the following statements must be considered:

- Intentions and perceptions must be assessed in relation to the particular behavior of interest;
- Intentions and perceived behavioral control must remain stable in the interval between their assessment and observation of the behavior (no upcoming events);
- The interaction of the above tools may vary in function of the type of intention: perceived behavioral control is the parameter of uncertainty of the performance of an action (like the confidence index in the BDI).

These characteristics influenced the creation of the model and the survey structure, in particular they affected the style of the questions. Each responder is invited to think about a specific situation and to use its mind when he/she has to take important decisions (like the first aid to a person): everybody wants to help a person in difficulty, but during the evacuation maybe it is not the better solution for the safety of both responder and injured.

6.2 Survey creation and distribution

The survey has been created online using GoogleForms, that permits to get answers in real time in an sorted and manageable way. It has been written in both Italian and English. A copy of the survey in both languages is available in Appendixes A and B. The survey has been sent by email and other internet-based instruments. In particular, it has been published in an internet website of an high school in Italy and it reached a lot of senior students, professors and staff. The survey reached 143 people in the U.S.A. (California) and Italy. Moreover, the reached people have different ages and nationalities, so the sample is nicely mixed. The results were recorded automatically on a GoogleSheet file then analyzed and managed on Microsoft Excel.

The survey is composed by eleven sections. Before filling in the questionnaire, in the first page responders are informed about reason and purpose of the research study. Privacy statement and contacts to request information are provided.

> *Extract from Page 1*
> *You have been invited to take part in a research study. The information in this form is provided to helps if you want to take part in this survey.*

What is the purpose of this research study?
The goal of this project is to use an emergency scenario survey that allow to analyze how people evaluate emergencies situations, in order to develop an accurate simulation model of an emergency evacuation, taking into an account human behavior, damage scenarios and parallel computing devices.

Will the information that is obtained from me be kept confidential? The personal information that you will be asked to give are age, sex and highest school degree, so your identity will not be known by the Principal Investigator. People who will have access to that information will be the research team members, specifically the Principal Investigator and the Advisors. Your responses will be confidential. You and your answers will not be identified in any reports or publications resulting from the study.

May I change my mind about participating?
Your participation in this study is voluntary. You may decide to not begin or to stop the study at any time by simply close the webpage.

Who can I contact for additional information?
You can obtain further information about the research or to voice concerns or complaints about this research by writing to the Principal Investigator: Alessio Vallero at alessio.vallero@studenti.polito.it.

Advice for the goal achievement
In order to achieve the goal of this survey, please answer all the questions by focusing on the situation that is described at the beginning of each section. Please follow each request you find during the questionnaire and answer with honesty (remember that nobody will know your identity). Please, do not complete the survey more than one time.

Sex, age and job of the sample are asked, in order to have those data for future improvements of the model. Results have been illustrated in the section above.

6.3 Psychological environments

The core of survey is composed of sections 4 to 11. They each represent a category of situations. In order to avoid repetitions, in this paragraph only one of these sections is reported. For a complete view and critique of the whole survey, the reader is invited to see Appendix 1 and 2. Each section is composed by a brief introduction, that presents the psychological context that the agent should be subject to. A drawing of the scene is also presented to the sample, in order to let him remember better the context while filling the survey section. As described in the previous chapter, each question has been written in order to better reduce the social desirability bias and to involve the responder to think about the presented situation according to TPB theory. The following example reports the fifth case of the survey.

Example

CASE 5 (Questions 13-16)
During the evacuation, you are with YOUR FAMILY or with your friends. Fortunately, you are not injured, so you can walk and run and you are able to see and hear well the most important things of the environment, even if there is crowd and smoke. Fortunately you see the emergency exit!

You are EVACUATING the building, but... DAMN! You can not find a member of your family/friends!!! What will you do?

1. *I will come back and look for the missing person.*
2. *Maybe I will come back and look for the missing person.*
3. *I don't know.*
4. *Maybe I will continue the evacuation: paramedics are more experienced than me, they will give him a better help.*
5. *I will continue the evacuation: paramedics are more experienced than me, they will give him a better help.*

You see a group of people running in a different direction respect the emergency exit one. How likely will you follow them?

1. *I will follow them: maybe they know a better exit!*
2. *Maybe I will follow them: maybe they know a better exit!*

3. *I don't know.*
4. *Maybe I will not follow them: I will exit on my own through the emergency exit!*
5. *I will not follow them: I will exit on my own through the emergency exit!*

You find a not seriously injured person. How likely will you give him a help (or first aid)?

1. *I will help him.*
2. *Maybe I will help him.*
3. *I don't know.*
4. *Maybe it's not necessary to help him: paramedics will arrive soon!*
5. *It's not necessary to help him: paramedics will arrive soon!*

You find a not seriously injured person. How likely will you give him a help (or first aid)?

1. *I will help him.*
2. *Maybe I will help him.*
3. *I don't know.*

4. *Maybe it's not necessary to help him: paramedics will arrive soon!*
5. *It's not necessary to help him: paramedics will arrive soon!*

6.4 Statistics and comments on survey answerers

6.4.1 Responders

The graph reported in Figure 6.1 illustrates the division of the sample in age intervals.

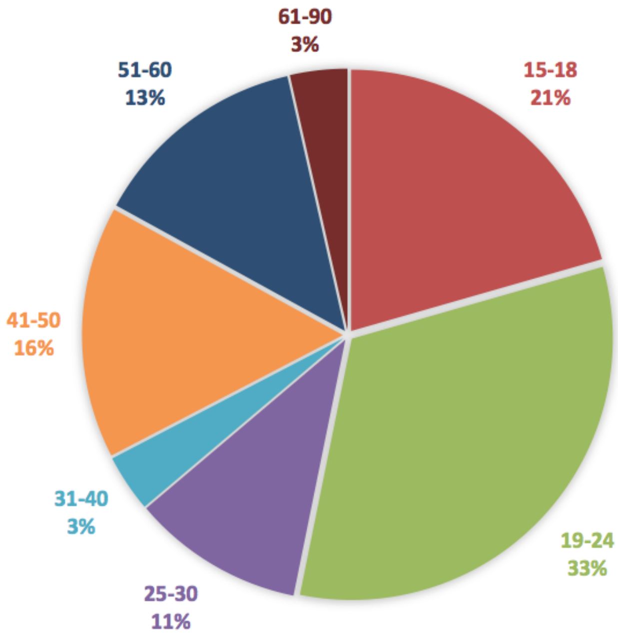


Figure 6.1: Age of responders.

The distribution of age in the sample does not follow the percentages of a specific building or population, because the survey was not treated as a simple random survey. Moreover, it includes personal data that will permit, in the future, the development of human behavior for a specific category of people (e.g. the behavior of a female student between 20 and 25 years old).

The information that has been presented in this paragraph is not considered in the model that has been created on the software because of the complexity of the implementation of those information. As written above, further developments are encouraged by using those data: the presence of other characteristics such as age and job will permit a refined pivoting of the sample.

6.4.2 Goals achievement

This paragraph aims to demonstrate the quality of the survey design. Answers are examined case by case. The following histograms report the probability to follow a group of people that is not moving in agent's prefered direction. Data are divided between cases in which people do not see the emergency exit and cases in which people see it.

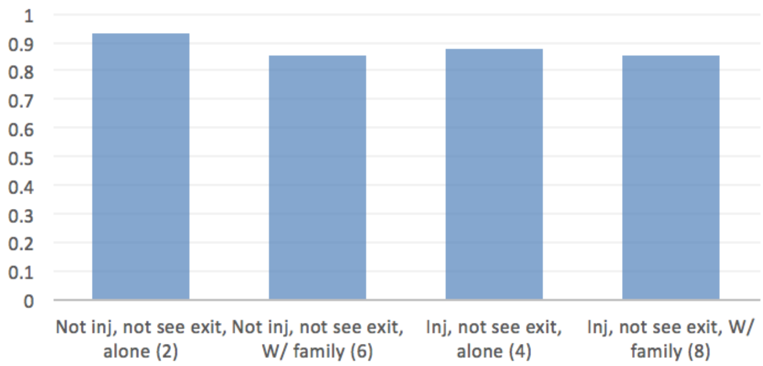


Figure 6.2: Probability of following a group of people, if agent does not see the emergency exit.

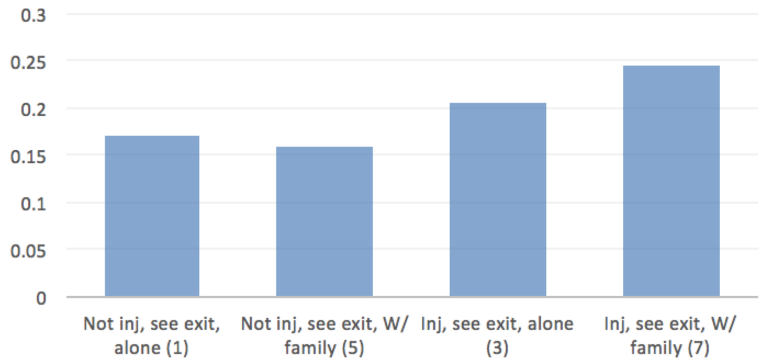


Figure 6.3: Probability of following a group of people, if agent is able to see the emergency exit.

Three considerations can be done:

- Most of the people tend to follow a group if they do not see the emergency exit.
- If agents are able to see the emergency exit and they are not injured or they are with their family/friends, they tend more to exit on their own. It is

the demonstration of the increase of "personality" in agents during specific situations.

- A higher number of people would follow a group of people if they are injured but they see the emergency exit. The increase is about 5-10% respect to the healthy people.

The following histograms report the willingness to help someone, depending on the state and the feelings of the agent.

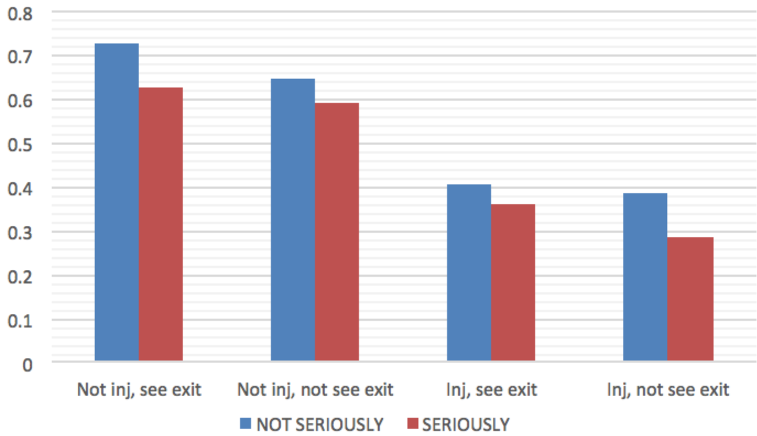


Figure 6.4: Probability of helping a seriously/not severely injured person (Alone case).

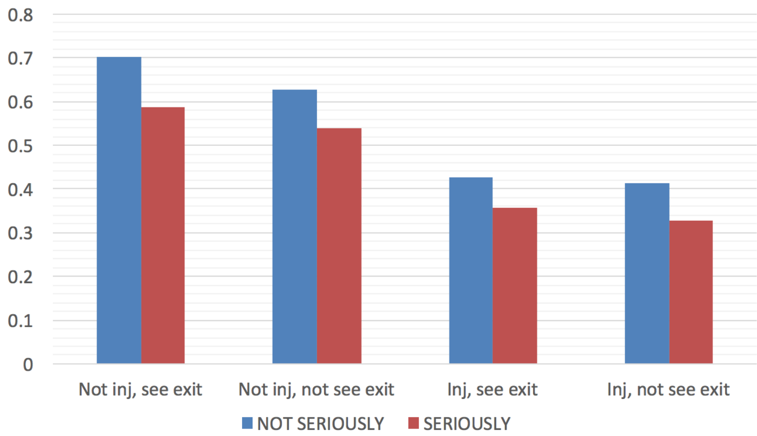


Figure 6.5: Probability of helping a seriously/not severely injured person (With family).

Three considerations can be done:

- Responders understood the difference between seriously and not seriously injured people;
- Responders understood the difficulty of helping someone if they are injured: in fact their willingness to help a person is extremely reduced in that case;
- Unfortunately, there are not differences between alone people or people with family/friends.

The last histogram this chapter reports is the willingness to look for a missing relative or friend: as expected, most of the interviewed people will look for him/her. 20% of responders would not look for the missing person if injured: it is the demonstration of the "selfish" behavior that some agents belong to specific categories of people.

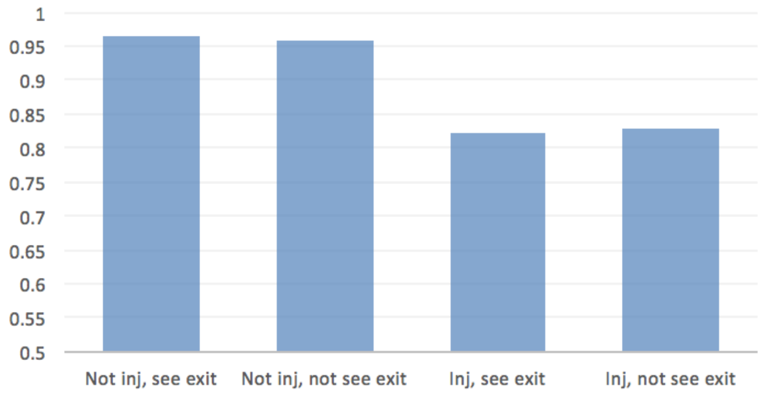


Figure 6.6: Probability of looking for a missing relative or friend.

6.5 Results for BDI model

6.5.1 Data treatment

Figure 6.7 reports how survey data have been treated. According to the guidelines in the previous sections, the following decisions have been applied:

- The probability of helping a person (seriously or not seriously injured) is chosen from a probability interval that is created by people who answered "Yes" and people who answered "Yes" and "Maybe yes".
- The probability of following a group of people is chosen from a probability interval that is created by people who answered "Yes" and "Maybe yes" and people who answered "Yes", "Maybe yes" and "I don't know".

- The probability of looking for a missing relative or friend is chosen from a probability interval that is created by people who answered "Yes" and "Maybe yes" and people who answered "Yes", "Maybe yes" and "I don't know".

The following Figure reports the data treatment for the first typology of agents. The complete database is available in Annex C.

CASE 1
ALONE
NOT INJURED
SEE EMERGENCY EXIT

QUESTION 1		
You see a group running in another direction		
ANSWER	COUNT	PROB
Follow	6	0.042
Maybe	16	0.112
Don'k know	6	0.042
Maybe no	59	0.413
Don't follow	56	0.392
TOT	143	1

QUESTION 2		
You see a not seriously injured person.		
ANSWER	COUNT	PROB
Help	84	0.587
Maybe	40	0.280
Don'k know	5	0.035
Maybe no	9	0.063
Don't help	5	0.035
TOT	143	1

QUESTION 3		
You see a seriously injured person		
ANSWER	COUNT	PROB
Help	78	0.545
Maybe	24	0.168
Don'k know	10	0.070
Maybe no	5	0.035
Don't help	26	0.182
TOT	143	1

Positive + Maybe	0.154
Positive+Maybe+I don't know	0.196

Positive	0.587
Positive + Maybe	0.867

Positive	0.545
Positive + Maybe	0.713

W vector evaluation

	Intervals		Question	Qn.
W=	0.154	0.196	Do you follow the group of people?	1
	0.587	0.867	Do you help a not seriously injured person?	2
	0.545	0.713	Do you help a seriously injured person?	3

	0.144
S*Wavg	0.647
	0.557

	0.031
Wavg-S*Wavg	0.081
	0.072

		Question	Qn.	T matrix		
Wavg=	0.175	Do you follow the group of people?	1	0.255	-0.010	-0.010
	0.727	Do you help a not seriously injured person?	2	-0.010	0.122	-0.010
	0.629	Do you help a seriously injured person?	3	-0.010	-0.010	0.129

Figure 6.7: Data treatment, Case 1.

6.5.2 Results

Results for Case 1.

$$T_1 = \begin{bmatrix} 0.255 & -0.01 & -0.01 \\ -0.01 & 0.122 & -0.01 \\ -0.01 & -0.01 & 0.129 \end{bmatrix}$$

$$W_{low,1} = \begin{bmatrix} 0.154 \\ 0.587 \\ 0.545 \end{bmatrix} ; W_{up,1} = \begin{bmatrix} 0.196 \\ 0.867 \\ 0.713 \end{bmatrix} ; W_{avg,1} = \begin{bmatrix} 0.175 \\ 0.727 \\ 0.629 \end{bmatrix}$$

Results for Case 2.

$$T_2 = \begin{bmatrix} 0.127 & -0.01 & -0.01 \\ -0.01 & 0.147 & -0.01 \\ -0.01 & -0.01 & 0.153 \end{bmatrix}$$

$$W_{low,2} = \begin{bmatrix} 0.930 \\ 0.524 \\ 0.510 \end{bmatrix}; W_{up,2} = \begin{bmatrix} 0.937 \\ 0.769 \\ 0.678 \end{bmatrix}; W_{avg,2} = \begin{bmatrix} 0.934 \\ 0.647 \\ 0.594 \end{bmatrix}$$

Results for Case 3.

$$T_3 = \begin{bmatrix} 0.171 & -0.01 & -0.01 \\ -0.01 & 0.128 & -0.01 \\ -0.01 & -0.01 & 0.134 \end{bmatrix}$$

$$W_{low,3} = \begin{bmatrix} 0.196 \\ 0.280 \\ 0.252 \end{bmatrix}; W_{up,3} = \begin{bmatrix} 0.238 \\ 0.538 \\ 0.476 \end{bmatrix}; W_{avg,3} = \begin{bmatrix} 0.217 \\ 0.409 \\ 0.364 \end{bmatrix}$$

Results for Case 4.

$$T_4 = \begin{bmatrix} 0.115 & -0.01 & -0.01 \\ -0.01 & 0.160 & -0.01 \\ -0.01 & -0.01 & 0.189 \end{bmatrix}$$

$$W_{low,4} = \begin{bmatrix} 0.853 \\ 0.273 \\ 0.210 \end{bmatrix}; W_{up,4} = \begin{bmatrix} 0.909 \\ 0.503 \\ 0.364 \end{bmatrix}; W_{avg,4} = \begin{bmatrix} 0.881 \\ 0.338 \\ 0.287 \end{bmatrix}$$

Results for Case 5.

$$T_5 = \begin{bmatrix} 0.130 & -0.01 & -0.01 & -0.01 \\ -0.01 & 0.374 & -0.01 & -0.01 \\ -0.01 & -0.01 & 0.149 & -0.01 \\ -0.01 & -0.01 & -0.01 & 0.162 \end{bmatrix}$$

$$W_{low,5} = \begin{bmatrix} 0.965 \\ 0.147 \\ 0.545 \\ 0.483 \end{bmatrix}; W_{up,5} = \begin{bmatrix} 0.965 \\ 0.182 \\ 0.860 \\ 0.692 \end{bmatrix}; W_{avg,5} = \begin{bmatrix} 0.965 \\ 0.164 \\ 0.703 \\ 0.587 \end{bmatrix}$$

Results for Case 6.

$$T_6 = \begin{bmatrix} 0.142 & -0.01 & -0.01 & -0.01 \\ -0.01 & 0.150 & -0.01 & -0.01 \\ -0.01 & -0.01 & 0.175 & -0.01 \\ -0.01 & -0.01 & -0.01 & 0.191 \end{bmatrix}$$

$$W_{low,6} = \begin{bmatrix} 0.951 \\ 0.825 \\ 0.483 \\ 0.434 \end{bmatrix} ; W_{up,6} = \begin{bmatrix} 0.1 \\ 0.1 \\ 0.1 \\ 0.1 \end{bmatrix} ; W_{avg,6} = \begin{bmatrix} 0.958 \\ 0.853 \\ 0.626 \\ 0.538 \end{bmatrix}$$

Results for Case 7.

$$T_7 = \begin{bmatrix} 0.125 & -0.01 & -0.01 & -0.01 \\ -0.01 & 0.230 & -0.01 & -0.01 \\ -0.01 & -0.01 & 0.167 & -0.01 \\ -0.01 & -0.01 & -0.01 & 0.184 \end{bmatrix}$$

$$W_{low,7} = \begin{bmatrix} 0.790 \\ 0.210 \\ 0.301 \\ 0.259 \end{bmatrix} ; W_{up,7} = \begin{bmatrix} 0.860 \\ 0.287 \\ 0.552 \\ 0.455 \end{bmatrix} ; W_{avg,7} = \begin{bmatrix} 0.825 \\ 0.248 \\ 0.427 \\ 0.357 \end{bmatrix}$$

Results for Case 8.

$$T_8 = \begin{bmatrix} 0.138 & -0.01 & -0.01 & -0.01 \\ -0.01 & 0.137 & -0.01 & -0.01 \\ -0.01 & -0.01 & 0.198 & -0.01 \\ -0.01 & -0.01 & -0.01 & 0.228 \end{bmatrix}$$

$$W_{low,8} = \begin{bmatrix} 0.804 \\ 0.825 \\ 0.287 \\ 0.245 \end{bmatrix} ; W_{up,8} = \begin{bmatrix} 0.860 \\ 0.881 \\ 0.538 \\ 0.413 \end{bmatrix} ; W_{avg,8} = \begin{bmatrix} 0.832 \\ 0.853 \\ 0.413 \\ 0.329 \end{bmatrix}$$

Chapter 7

Damage Scenarios and Case Study

This Chapter describes a case study of this research. The environment was created using PACT, a software that is able to output the damage scenario starting from structure, structural analysis and population definition.

7.1 The structure

This section aims to give a quick overview of all the previous work that has been done by the Pacific Earthquake Engineering Research Center (PEER, UC Berkeley) for designing the structure according to modern American standards and policies. The case study is a three story building, with steel structure, located in Oakland (CA). The building was originally planned to be built in Los Angeles (CA) by Forell/Ellsner Engineers (Structural Engineering company, San Francisco, CA).

The project location (and consequently its design) was moved to Oakland (CA) and the PEER developed it with a large number of traditional and experimental anti-seismic tools for research purposes. The design for this case study has been made by Benshun Shao (PhD Candidate, UC Berkeley). The building has been designed with base isolation through a Single Friction Pendulum Bearing available in commerce. Measurements units that were used in this design are Imperial, but in this thesis they are also translated according to the International System (Metric). Building dimensions are:

- 180’ x 120’ (ft) in plan (54.9 x 36.6 m);
- Equal spans of 30’-0” (914 cm);
- Equal story heights of 15’-0” (457 cm);

- Masses are equal for each story.

The sections being used are reported in Table 7.1. American Policies requirements have been satisfied and all simulations have been performed through OpenSees (PEER). The following subsections describe the structural model.

Explanation	Area [in^2]	AISC Name	I_x [in^4]	Z_x [in^3]	d [in]	b_f [in]	t_f [in]	t_w [in]
First story column	42.7	W14x145	1710	260	14.8	15.5	1.09	0.68
Second story column	42.7	W14x145	1710	260	14.8	15.5	1.09	0.68
Third story column	26.5	W14x90	999	157	14	14.5	0.71	0.44
Base beam	20.1	W24x68	1830	177	23.7	8.97	0.585	0.415
First story beam	20.1	W24x68	1830	177	23.7	8.97	0.585	0.415
Second story beam	18.2	W24x62	1550	153	23.7	7.04	0.59	0.43
Third story beam	13.5	W18x46	712	90.7	18.1	6.06	0.605	0.36

Explanation	Area [mm^2]	AISC Name	I_x [mm^4]	Z_x [mm^3]	d [mm]	b_f [mm]	t_f [mm]	t_w [mm]
First story column	27548.3	W14x145	7.1E+08	4.3E+06	375.9	393.7	27.7	17.3
Second story column	27548.3	W14x145	7.1E+08	4.3E+06	375.9	393.7	27.7	17.3
Third story column	17096.7	W14x90	4.2E+08	2.6E+06	355.6	368.3	18.0	11.2
Base beam	12967.7	W24x68	7.6E+08	2.9E+06	602.0	227.8	14.9	10.5
First story beam	12967.7	W24x68	7.6E+08	2.9E+06	602.0	227.8	14.9	10.5
Second story beam	11741.9	W24x62	6.4E+08	2.5E+06	602.0	178.8	15.0	10.9
Third story beam	8709.7	W18x46	3.0E+08	1.5E+06	459.7	153.9	15.4	9.1

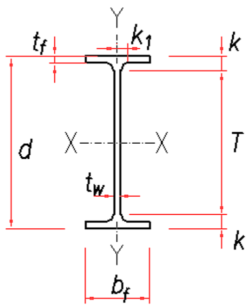


Table 7.1: Columns and beams sections. (Figure from www.structural-drafting-net-expert.com/steel-sections-i-beam-w-shape.html)

7.1.1 Ground motion selection

USGS (U.S. Geological Survey) policies describe how to define the target spectrum at MCE (Maximum Considered Earthquake) level. MCE target spectrum has the probability of exceedance set at the value of 2% in 50 years. After having defined the target spectrum for Oakland (CA), PEER assumed the 16 ground motions available in literature that best fitted the target spectrum. PACT software requires an acceptable value of earthquake scenarios, so the ground motions were scaled in order to define 10 different levels. 10 scenarios have been created and simulated through OpenSees (Mazzoni, 2006 [39]) and their ground motion factor (GM) varies between 0.3 and 1.2. It is important to denote that GM=0.5 corresponds to the DBE (Design Basis Earthquake), that is the probability of exceedance of 10% in 50 years. DBE values are necessary for the bearing performance requirements.

7.1.2 Bearings

This case study involved the usage of single friction pendulum bearings, designed by Earthquake Protection Systems, Inc. (Mission Vallejo, CA). Bearings design consists of a starting point of plastic deformation at 8% of the weight on each of them. Their period is 3.0 sec at DBE. According to ASCE 7-10, the seismic gap of the bearings is set considering the average displacement given by each ground motion at the MCE level and its value is 25 inches (63.5 cm).

7.1.3 MAFE

The Mean Annual Frequency of Exceedance (MAFE) is a parameter that is required by PACT software. Its value can be determined through USGS policies by using the spectral acceleration at the value of fundamental period. A MAFE curve was determined by using all the accelerations for each scenario/intensity level.

7.1.4 Structural analysis results

Structural analysis has been done through the nonlinear time-history option of OpenSees and the results are available in Appendix D. It is important to notice an extremely high increase of the acceleration values at GM=1.1 and 1.2. As mentioned before, the seismic gap of FPBs is designed at the MCE level (GM=1.0), so for higher intensities the FPB displacements would be higher than the maximum space available. The result is a strong hardening phenomenon that gives a motivation to the high values of acceleration. Obviously, in reality, these accelerations are not occurring because of the failure of bearing components: it is a limit of the model.

7.2 Building plan

This section describes choices and assumptions taken for the creation of the building plan. According to the Repast HPC requirements, the plan has been designed as a grid of square cells. The assumed dimension of a cell is 30 cm, that is the smallest admissible length in the project.

Even if the structure was created as office building, this research designed the first floor as a retail area. The following points describes the design choices made for the floors:

- The ground floor is a big supermarket (having the characteristic long and thick storage racks) and five small shops.
- The second floor is composed by six apartments, which are divided in small office rooms. They include restrooms and storage rooms.
- The third floor has been designed to be equal to the second one.

Each floor has a lot of non structural components, like desks, shelves and racks. According to the Repast HPC requirements, their dimensions have been chosen as follows:

- Internal and external walls, in black, have a thickness of one cell (30 cm);
- Wardrobes and office and retail desks are coloured in blue and they have standard dimensions;
- Bookshelves and filing cabinets have a thickness of 30 and 60 cm;
- Storage racks, in blue, have a thichness of 60 cm and in the retail floor they are sometimes coupled.

All the building plans are available in Annex E. The following Figure reports an example of one of the small shops of the ground floor.

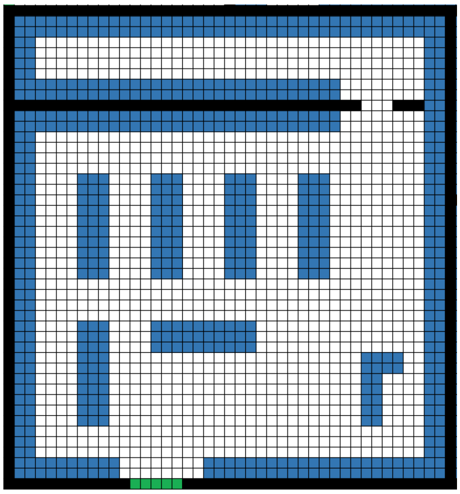


Figure 7.1: Example of the plan

7.3 PACT - Performance Assessment Calculation Tool

The Federal Emergency Management Agency (FEMA, U.S.A.) created a software to allow earthquake damage evaluation called *Performance Assessment Calculation Tool* (*PACT*). It is an electronic calculation tool and repository of fragility and consequence data, that performs the probabilistic calculations and accumulation of losses. It is described in the FEMA P-58 publications (see FEMA, 2012 [20]

[21]). It includes a series of utilities used to specify building properties and update or modify fragility and consequence information in the referenced databases. The following sections report the used software windows.

7.3.1 Project Information

This window is used as a project title and brief description. It does not contain any technical information about the assessment simulation.

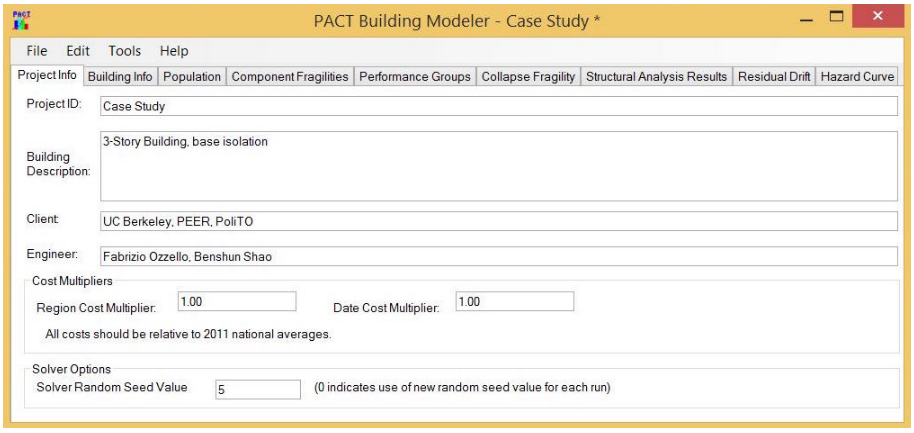


Figure 7.2: Project Information assignments [Source: PACT]

7.3.2 Building Information

PACT uses the Number of Stories input as a basic index for demand parameters, performance groups and calculations to be performed. A story is defined as the building volume that extends from the top of slab or other flooring at one floor level, to the top of slab or flooring at the next level. It includes all things that are mounted on or above the lower floor and which are present beneath the higher level, such as the framing supporting top floor or roof. The input value should include all stories that contains vulnerable components and which are to be included in the performance assessment. If basements are present, and contains vulnerable structural or nonstructural components or occupants susceptible to injury, these should be included as stories. Similarly, penthouses with vulnerable components or occupants should be included as stories. PACT defines the number of floors based on the Number of Stories input, where floor identifies all those components present within a story that are located on top of the surface of the identified floor, and beneath the top surface of the floor above. Thus, the first floor includes fragility groups for framing that supports the second floor; as well as components that are supported on the first floor or suspended from the second floor. Information related to stories and building dimensions are:

- Floor area
- Story height

Those information can be modified for each floor and their properties contains the following information:

- Height Factor is used to reflect increases in repair cost attributable to a lot of different causes, including the presence of complex systems (like elevator components) that can create an obstacle during the work;
- Hazmat factor, which takes into account the presence of dangerous material such as asbestos;
- Occupancy factor, which takes into account works that are done when the building is already occupied by users.

In this section there is also the possibility to insert other information about:

- Replacement time;
- Maximum workers per square foot;
- Core and shell replacement cost;
- Total replacement cost;
- Total loss threshold.

This data is very important for loss analyses, but they have not been used for this application. The following list reports the choices made for this research:

- Floor area: 21600 sq. ft for the first floor and 19000 sq. ft for the second and third floors. The reduction of the area of the second and third floor are due by the four squares in the building;
- Story height: 15 ft.

The following screenshot reports these choices in PACT.

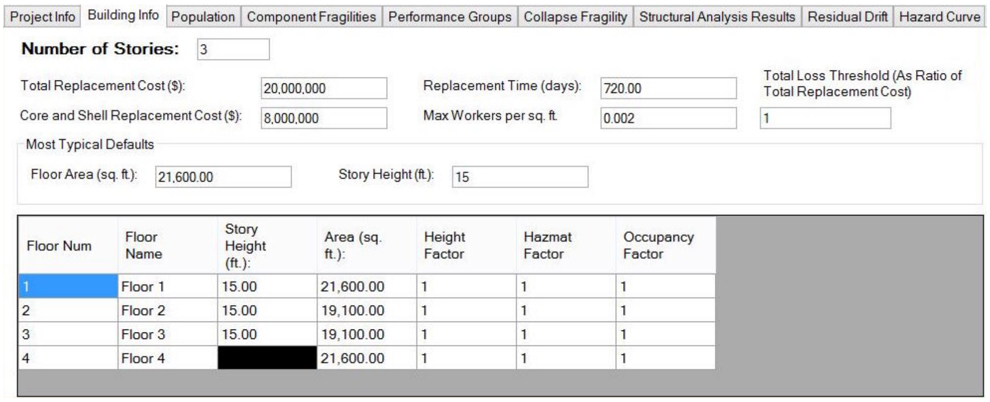


Figure 7.3: Building Information assignments [Source: PACT]

7.3.3 Population model

To assess casualties, users must define the population model, that is defined as the distribution of occupants within the building at various times of day. With PACT, it is possible to use one of the provided building population models or develop and input building-specific models. Eight population models are provided in PACT corresponding to typical commercial office, education (elementary, middle, high school), healthcare, hospitality, multi-unit residential, research, retail, and warehouse occupancies. Users can assign separate population models to several fractions of each floor level. Each population model includes the hourly distribution of people per 1,000 square feet for weekdays or weekends and can be adjusted to include further variation by month. The provided population models can be used directly or modified to reflect the unique occupancy characteristics of a specific building, if known.

In literature there are different values of maximum densities for each typology of building. The project assumed the following maximum densities for the standard PACT curves:

- 0.2 agents/m^2 for retail areas, which means approximately 20 agents/1000 ft^2. The peak value of agents in the ground floor will be 380;
- 0.1 agents/m^2 for office areas, which means approximately 10 agents/1000 ft^2. The peak value of agents in the first and floor will be 185 each.

The following figure illustrates the retail occupancy provided in PACT. The graph reports hourly occupancy during the weekends.

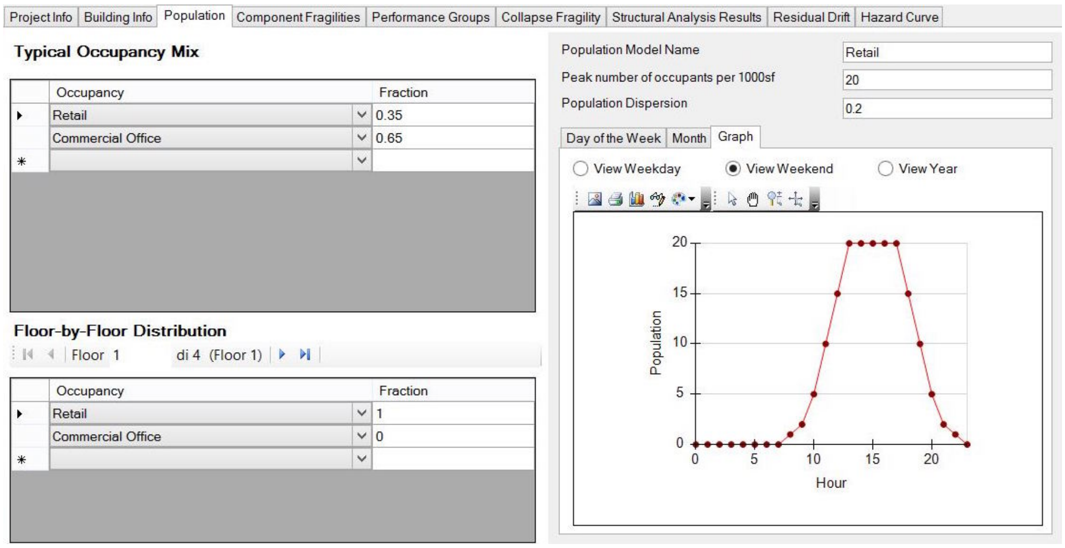


Figure 7.4: Population assignments [Source: PACT]

7.3.4 Fragility Specifications and Performance Groups

Following the definition of the general building characteristics, it is necessary to define quantity, vulnerability, and distribution of damageable components and contents. PACT organizes this process in two parts:

- identification of required fragility specifications for each floor;
- identification of the quantity of components in each performance group at each floor.

The fragility specification includes a description of the demand parameter that predicts damage, the types of damage that can occur, fragility functions, which indicate the probability of incurring each damage state as a function of demand, and consequence functions, which indicate the probable values of loss that will occur as a result of each damage state. Each fragility function specifies damage state probabilities for a single demand parameter. Typically, peak story drift ratio or peak floor acceleration parameters are used to determine if a component is damaged. The demand parameter can have a specific orientation with respect to the component (directional demand) or the demand can be non-directional. For example, wall elements will typically be damaged by story drift within their plane, where suspended ceiling systems are susceptible to damage from floor acceleration independent of horizontal direction.

A performance group is a set of components described by a single fragility group that will experience the same demand. Performance groups are ordered by the direction of application of their common demand parameter. In PACT, components can be selected and distributed across the building's floors to create a complete representation of the damageable building.

PACT does not include all vulnerable building components that may be present in a building, but it gives indications of typical components and quantities. Quantities can be estimated through an *Excel* spreadsheet called *Normative Quantity Estimation Tool*. By inserting dimensions and use of the building, that spreadsheet has given the quantities that are reported in Figure 7.6.

Because of the limited computational capacity of PACT, the expected detail level of the work and the awareness of having well designed structural components, this research took into consideration only the non-structural components. The modeled components are the following:

- Curtain walls;
- Wall partitions (full height);
- Wall partitions (partial height, not connected at the top);
- Stairs, made of precast concrete;
- Raised access floor;
- Suspended ceiling;
- Cold water piping
- Sanitary waste piping;
- HVAC metal ducts;
- Fire sprinkler water piping;
- Fire sprinkler drops;
- Modular office work stations;
- Desktop electronics;
- Bookcases;
- Storage racks;
- Unsecured fragile objects on shelves;
- Filing cabinets.

COMPONENT SUMMARY MATRIX

OCCUPANCY				Fragility Number	Fragility Name	Assumed Quantity per component within PACT	Quantity		Correlated Fragility?	Actual Quantity		PACT Basic Unit	Fragility Quantity Beta (LogNormal Distribution)
Type	Occupancy #	Floor Name	Component Area (sq ft)				Directional	Non Directional		Value	Unit		
START OF STANDARD INPUT													
OFFICE	1	3rd	19000	B2022.001	B2022.001 Curtain Walls - Generic Midrise Stick-Built Curtain wall, Config: Monolithic, Lamination: Unknown, Glass Type: Unknown, Details: Aspect ratio = 6:5, Other details Unknown	30 SF	190	–	NO	5700	SF	OK	0.6
OFFICE	1	3rd	19000	B3011.011	B3011.011 Concrete tile roof, tiles secured and compliant with UBC94	100 SF	–	51.3	NO	5130	SF	OK	1.3
OFFICE	1	3rd	19000	C1011.001a	C1011.001a Wall Partition, Type: Gypsum with metal studs, Full Height, Fixed Below, Fixed Above	100 LF	19	–	NO	1900	LF	OK	0.2
OFFICE	1	3rd	19000	C3011.001a	C3011.001a Wall Partition, Type: Gypsum + Wallpaper, Full Height, Fixed Below, Fixed Above	100 LF	1.4364	–	NO	143.64	LF	OK	0.7
OFFICE	1	3rd	19000	C3027.001	C3027.001 Raised Access Floor, non seismically rated.	100 SF	–	142.5	NO	14250	SF	OK	0.2
OFFICE	1	3rd	19000	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B, Area (A): A < 250, Vert support only	250 SF	–	68.4	NO	17100	SF	OK	0
OFFICE	1	3rd	19000	E2022.001	E2022.001 Modular office work stations.	1 EA	–	133	NO	133	EA	OK	0.2
OFFICE	1	3rd	19000	E2022.112a	E2022.112a Vertical Filing Cabinet, 2 drawer, unanchored laterally	1 EA	–	15.2	NO	15.2	EA	OK	0.6
OFFICE	1	3rd	19000	E2022.102a	E2022.102a Bookcase, 2 shelves, unanchored laterally	1 EA	–	38	NO	38	EA	OK	0.6
OFFICE	1	3rd	19000	D2021.011a	D2021.011a Cold Water Piping (dia > 2.5 inches), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.285	NO	285	LF	OK	0.2
OFFICE	1	3rd	19000	D2022.011a	D2022.011a Hot Water Piping - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC A or B, PIPING FRAGILITY	1000 LF	–	1.596	0	1596	LF	OK	0.7
OFFICE	1	3rd	19000	D2022.021a	D2022.021a Hot Water Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.57	0	570	LF	OK	0.2
OFFICE	1	3rd	19000	D2031.011b	D2031.011b Sanitary Waste Piping - Cast Iron w/flexible couplings, SDC A,B, BRACING FRAGILITY	1000 LF	–	1.083	0	1083	LF	OK	0.6
OFFICE	1	3rd	19000	D3041.012a	D3041.012a HVAC Galvanized Sheet Metal Ducting - 6 sq. ft cross sectional area or greater, SDC A or B	1000 LF	–	0.38	NO	380	LF	OK	0.2
OFFICE	1	3rd	19000	D3041.011a	D3041.011a HVAC Galvanized Sheet Metal Ducting less than 6 sq. ft in cross sectional area, SDC A or B	1000 LF	–	1.425	NO	1425	LF	OK	0.2
OFFICE	1	3rd	19000	D3041.031a	D3041.031a HVAC Drops / Diffusers in suspended ceilings - No independent safety wires, SDC A or B	10 EA	–	17.1	NO	171	EA	OK	0.5
OFFICE	1	3rd	19000	D3041.041a	D3041.041a Variable Air Volume (VAV) box with in-line coil, SDC A or B	10 EA	–	9.5	NO	95	EA	OK	0.2
OFFICE	1	3rd	19000	D3041.041a	D3041.041a Variable Air Volume (VAV) box with in-line coil, SDC A or B	10 EA	–	3.8	NO	38	EA	OK	0.5
OFFICE	1	3rd	19000	D2022.011a	D2022.011a Hot Water Piping - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.095	0	95	LF	OK	0.2
OFFICE	1	3rd	19000	D2022.021a	D2022.021a Hot Water Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.095	0	95	LF	OK	0.2
OFFICE	1	3rd	19000	C3033.001	C3033.001 Recessed lighting in suspended ceiling - no independent support wires	1 EA	–	285	NO	285	EA	OK	0.3
OFFICE	1	3rd	19000	C3034.001	C3034.001 Independent Pendant Lighting - non seismic	1 EA	–	285	NO	285	EA	OK	0.3
OFFICE	1	3rd	19000	D4011.021a	D4011.021a Fire Sprinkler Water Piping - Horizontal Mains and Branches - Old Style Victaulic - Thin Wall Steel - No bracing, SDC A or B, PIPING FRAGILITY	1000 LF	–	3.8	NO	3800	LF	OK	0.1
OFFICE	1	3rd	19000	D4011.031a	D4011.031a Fire Sprinkler Drop Standard Threaded Steel - Dropping into unbraced lay-in tile SOFT ceiling - 6 ft. long drop maximum, SDC A or B	100 EA	–	1.71	NO	171	EA	OK	0.2
OFFICE	1	2nd	19000	B2022.001	B2022.001 Curtain Walls - Generic Midrise Stick-Built Curtain wall, Config: Monolithic, Lamination: Unknown, Glass Type: Unknown, Details: Aspect ratio = 6:5, Other details Unknown	30 SF	190	–	NO	5700	SF	OK	0.6
OFFICE	1	2nd	19000	B3011.011	B3011.011 Concrete tile roof, tiles secured and compliant with UBC94	100 SF	–	51.3	NO	5130	SF	OK	1.3
OFFICE	1	2nd	19000	C1011.001a	C1011.001a Wall Partition, Type: Gypsum with metal studs, Full Height, Fixed Below, Fixed Above	100 LF	19	–	NO	1900	LF	OK	0.2
OFFICE	1	2nd	19000	C3011.001a	C3011.001a Wall Partition, Type: Gypsum + Wallpaper, Full Height, Fixed Below, Fixed Above	100 LF	1.4364	–	NO	143.64	LF	OK	0.7
OFFICE	1	2nd	19000	C3027.001	C3027.001 Raised Access Floor, non seismically rated.	100 SF	–	142.5	NO	14250	SF	OK	0.2
OFFICE	1	2nd	19000	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B, Area (A): A < 250, Vert support only	250 SF	–	68.4	NO	17100	SF	OK	0
OFFICE	1	2nd	19000	E2022.001	E2022.001 Modular office work stations.	1 EA	–	133	NO	133	EA	OK	0.2
OFFICE	1	2nd	19000	E2022.112a	E2022.112a Vertical Filing Cabinet, 2 drawer, unanchored laterally	1 EA	–	15.2	NO	15.2	EA	OK	0.6
OFFICE	1	2nd	19000	E2022.102a	E2022.102a Bookcase, 2 shelves, unanchored laterally	1 EA	–	38	NO	38	EA	OK	0.6
OFFICE	1	2nd	19000	D2021.011a	D2021.011a Cold Water Piping (dia > 2.5 inches), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.285	NO	285	LF	OK	0.2
OFFICE	1	2nd	19000	D2022.011a	D2022.011a Hot Water Piping - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC A or B, PIPING FRAGILITY	1000 LF	–	1.596	0	1596	LF	OK	0.7
OFFICE	1	2nd	19000	D2022.021a	D2022.021a Hot Water Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.57	0	570	LF	OK	0.2
OFFICE	1	2nd	19000	D2031.011b	D2031.011b Sanitary Waste Piping - Cast Iron w/flexible couplings, SDC A,B, BRACING FRAGILITY	1000 LF	–	1.083	0	1083	LF	OK	0.6
OFFICE	1	2nd	19000	D3041.012a	D3041.012a HVAC Galvanized Sheet Metal Ducting - 6 sq. ft cross sectional area or greater, SDC A or B	1000 LF	–	0.38	NO	380	LF	OK	0.2
OFFICE	1	2nd	19000	D3041.011a	D3041.011a HVAC Galvanized Sheet Metal Ducting less than 6 sq. ft in cross sectional area, SDC A or B	1000 LF	–	1.425	NO	1425	LF	OK	0.2
OFFICE	1	2nd	19000	D3041.031a	D3041.031a HVAC Drops / Diffusers in suspended ceilings - No independent safety wires, SDC A or B	10 EA	–	17.1	NO	171	EA	OK	0.5

Figure 7.5: Performance Groups suggested quantities - Part 1. [Source: PACT]

OFFICE	1	2nd	19000	D2022.011a	D2022.011a Hot Water Piping - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.095	0	95	LF	OK	0.2
OFFICE	1	2nd	19000	D2022.021a	D2022.021a Hot Water Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.095	0	95	LF	OK	0.2
OFFICE	1	2nd	19000	C3033.001	C3033.001 Recessed lighting in suspended ceiling - no independent support wires	1 EA	–	285	NO	285	EA	OK	0.3
OFFICE	1	2nd	19000	C3034.001	C3034.001 Independent Pendant Lighting - non seismic	1 EA	–	285	NO	285	EA	OK	0.3
OFFICE	1	2nd	19000	D4011.021a	D4011.021a Fire Sprinkler Water Piping - Horizontal Mains and Branches - Old Style Victaulic - Thin Wall Steel - No bracing, SDC A or B, PIPING FRAGILITY	1000 LF	–	3.8	NO	3800	LF	OK	0.1
OFFICE	1	2nd	19000	D4011.031a	D4011.031a Fire Sprinkler Drop Standard Threaded Steel - Dropping into unbraced lay-in tile SOFT ceiling - 6 ft. long drop maximum, SDC A or B	100 EA	–	1.71	NO	171	EA	OK	0.2
RETAIL	1	1st	21600	B2022.001	B2022.001 Curtain Walls - Generic Midrise Stick-Built Curtain wall, Config: Monolithic, Lamination: Unknown, Glass Type: Unknown, Details: Aspect ratio = 6:5, Other details Unknown	30 SF	43.2	–	NO	1296	SF	OK	0.3
RETAIL	1	1st	21600	B3011.011	B3011.011 Concrete tile roof, tiles secured and compliant with UBC94	100 SF	–	108	NO	10800	SF	OK	p90 low
RETAIL	1	1st	21600	C1011.001a	C1011.001a Wall Partition, Type: Gypsum with metal studs, Full Height, Fixed Below, Fixed Above	100 LF	2.16	–	NO	216	LF	OK	0.2
RETAIL	1	1st	21600	C3011.001a	C3011.001a Wall Partition, Type: Gypsum + Wallpaper, Full Height, Fixed Below, Fixed Above	100 LF	2.3328	–	NO	233.28	LF	OK	0.2
RETAIL	1	1st	21600	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B, Area (A): A < 250, Vert support only	250 SF	–	77.76	NO	19440	SF	OK	0
RETAIL	1	1st	21600	D2021.011a	D2021.011a Cold Water Piping (dia > 2.5 inches), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.324	NO	324	LF	OK	0.2
RETAIL	1	1st	21600	D2022.011a	D2022.011a Hot Water Piping - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC A or B, PIPING FRAGILITY	1000 LF	–	1.296	0	1296	LF	OK	0.3
RETAIL	1	1st	21600	D2022.021a	D2022.021a Hot Water Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.648	0	648	LF	OK	0.2
RETAIL	1	1st	21600	D3041.012a	D3041.012a HVAC Galvanized Sheet Metal Ducting - 6 sq. ft cross sectional area or greater, SDC A or B	1000 LF	–	1.08	NO	1080	LF	OK	0.6
RETAIL	1	1st	21600	D3041.011a	D3041.011a HVAC Galvanized Sheet Metal Ducting less than 6 sq. ft in cross sectional area, SDC A or B	1000 LF	–	0.108	NO	108	LF	OK	0.2
RETAIL	1	1st	21600	D3041.041a	D3041.041a Variable Air Volume (VAV) box with in-line coil, SDC A or B	10 EA	–	8.64	NO	86.4	EA	OK	p90 low
RETAIL	1	1st	21600	D2061.023a	D2061.023a Steam Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC D, E, or F, PIPING FRAGILITY	1000 LF	–	0.108	NO	108	LF	OK	0.2
RETAIL	1	1st	21600	D2022.011a	D2022.011a Hot Water Piping - Small Diameter Threaded Steel - (2.5 inches in diameter or less), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.54	0	540	LF	OK	0.6
RETAIL	1	1st	21600	D2022.021a	D2022.021a Hot Water Piping - Large Diameter Welded Steel - (greater than 2.5 inches in diameter), SDC A or B, PIPING FRAGILITY	1000 LF	–	0.108	0	108	LF	OK	0.2
RETAIL	1	1st	21600	C3033.001	C3033.001 Recessed lighting in suspended ceiling - no independent support wires	1 EA	–	324	NO	324	EA	OK	0.2
RETAIL	1	1st	21600	C3034.001	C3034.001 Independent Pendant Lighting - non seismic	1 EA	–	324	NO	324	EA	OK	0.2
RETAIL	1	1st	21600	D4011.021a	D4011.021a Fire Sprinkler Water Piping - Horizontal Mains and Branches - Old Style Victaulic - Thin Wall Steel - No bracing, SDC A or B, PIPING FRAGILITY	1000 LF	–	3.888	NO	3888	LF	OK	0.1
RETAIL	1	1st	21600	D4011.031a	D4011.031a Fire Sprinkler Drop Standard Threaded Steel - Dropping into unbraced lay-in tile SOFT ceiling - 6 ft. long drop maximum, SDC A or B	100 EA	–	1.728	NO	172.8	EA	OK	0.2
END OF STANDARD INPUT													
START OF FLOOR SUM INPUT													
ALL	ALL	3rd	FLOOR	C2011.001a	C2011.001a Prefabricated steel stair with steel treads and landings with seismic joints that accommodate drift.	1 EA	2	–	NO	1.9	EA	OK	0.2
ALL	ALL	3rd	FLOOR	D5012.021a	D5012.021a Low Voltage Switchgear - Capacity: 100 to <350 Amp - Unanchored equipment that is not vibration isolated - Equipment fragility only	225 AP	–	1	NO	5.7	AP	OK	0.4
ALL	ALL	2nd	FLOOR	C2011.001a	C2011.001a Prefabricated steel stair with steel treads and landings with seismic joints that accommodate drift.	1 EA	2	–	NO	1.9	EA	OK	0.2
ALL	ALL	2nd	FLOOR	D5012.021a	D5012.021a Low Voltage Switchgear - Capacity: 100 to <350 Amp - Unanchored equipment that is not vibration isolated - Equipment fragility only	225 AP	–	1	NO	5.7	AP	OK	0.4
ALL	ALL	1st	FLOOR	C2011.001a	C2011.001a Prefabricated steel stair with steel treads and landings with seismic joints that accommodate drift.	1 EA	3	–	NO	2.16	EA	OK	0.3
ALL	ALL	1st	FLOOR	D5012.021a	D5012.021a Low Voltage Switchgear - Capacity: 100 to <350 Amp - Unanchored equipment that is not vibration isolated - Equipment fragility only	225 AP	–	1	NO	6.48	AP	OK	0.4
END OF FLOOR SUM INPUT													
START OF BUILDING SUM INPUT													
ALL	ALL	ALL	BLDG	D1014.011	D1014.011 Traction Elevator – Applies to most California Installations 1976 or later, most western states installations 1982 or later and most other U.S installations 1998 or later.	1 EA	–	4	NO	3.224	EA	OK	0.3
ALL	ALL	ALL	BLDG	D3031.011a	D3031.011a Chiller - Capacity: < 100 Ton - Unanchored equipment that is not vibration isolated - Equipment fragility only	75 TN	–	2	NO	108.3	TN	OK	0.1
ALL	ALL	ALL	BLDG	D3031.021a	D3031.021a Cooling Tower - Capacity: < 100 Ton - Unanchored equipment that is not vibration isolated - Equipment fragility only	75 TN	–	2	NO	108.3	TN	OK	0.1
ALL	ALL	ALL	BLDG	D3052.011a	D3052.011a Air Handling Unit - Capacity: <5000 CFM - Unanchored equipment that is not vibration isolated - Equipment fragility only	4000 CF	–	7	NO	26600	CF	OK	0.2
ALL	ALL	ALL	BLDG	D5012.013a	D5012.013a Motor Control Center - Capacity: all - Unanchored equipment that is not vibration isolated Equipment fragility only	1 EA	–	2	NO	1.52	EA	OK	0.5
END OF BUILDING SUM INPUT													

Figure 7.6: Performance Groups suggested quantities - Part 2. [Source: PACT]

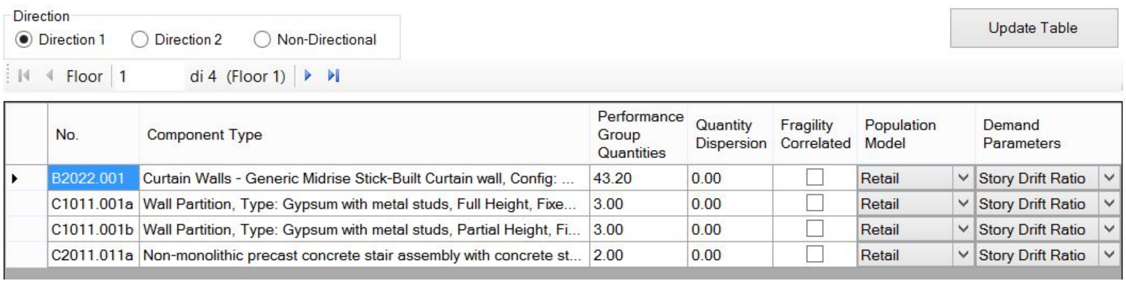
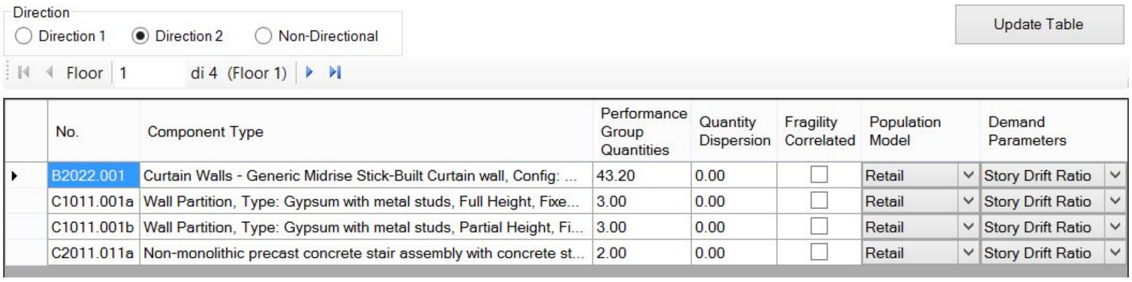
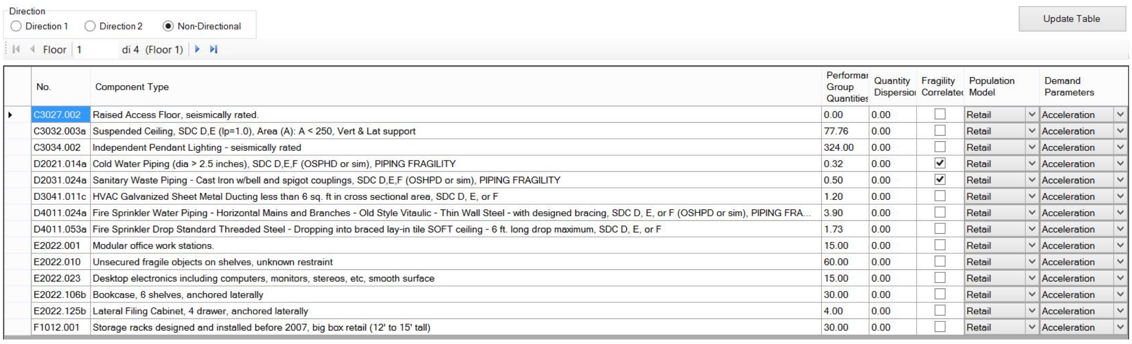


Figure 7.7: Performance Groups specification: floor 1, direction 1. [Source: PACT]



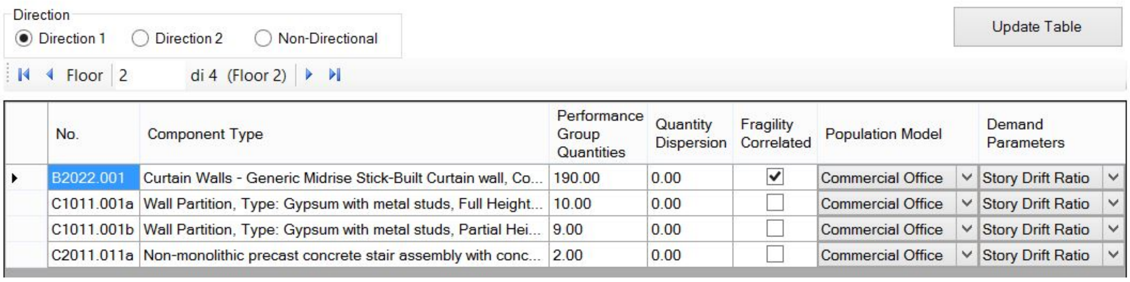
No.	Component Type	Performance Group Quantities	Quantity Dispersion	Fragility Correlated	Population Model	Demand Parameters
B2022.001	Curtain Walls - Generic Midrise Stick-Built Curtain wall, Config: ...	43.20	0.00	☐	Retail	Story Drift Ratio
C1011.001a	Wall Partition, Type: Gypsum with metal studs, Full Height, Fixe...	3.00	0.00	☐	Retail	Story Drift Ratio
C1011.001b	Wall Partition, Type: Gypsum with metal studs, Partial Height, Fi...	3.00	0.00	☐	Retail	Story Drift Ratio
C2011.011a	Non-monolithic precast concrete stair assembly with concrete st...	2.00	0.00	☐	Retail	Story Drift Ratio

Figure 7.8: Performance Groups specification: floor 1, direction 2. [Source: PACT]



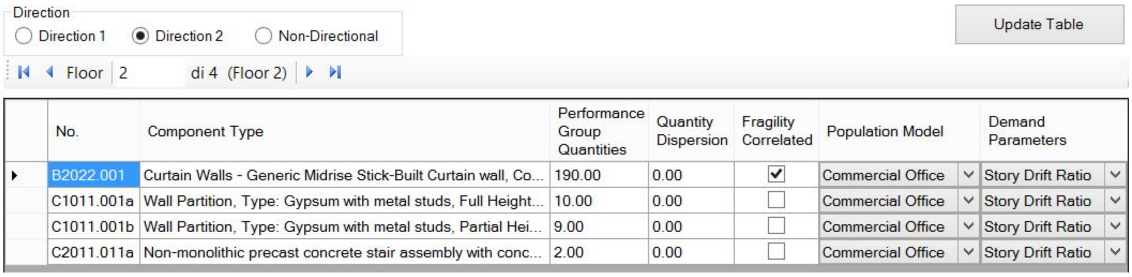
No.	Component Type	Performance Group Quantities	Quantity Dispersion	Fragility Correlated	Population Model	Demand Parameters
C3027.002	Raised Access Floor, seismically rated.	0.00	0.00	☐	Retail	Acceleration
C3032.003a	Suspended Ceiling, SDC D,E (Ip=1.0), Area (A): A < 250, Vert & Lat support	77.76	0.00	☐	Retail	Acceleration
C3034.002	Independent Pendant Lighting - seismically rated	324.00	0.00	☐	Retail	Acceleration
D2021.014a	Cold Water Piping (dia > 2.5 inches), SDC D,E,F (OSPHD or sim), PIPING FRAGILITY	0.32	0.00	☑	Retail	Acceleration
D2031.024a	Sanitary Waste Piping - Cast Iron w/bell and spigot couplings, SDC D,E,F (OSHPD or sim), PIPING FRAGILITY	0.50	0.00	☑	Retail	Acceleration
D3041.011c	HVAC Galvanized Sheet Metal Ducting less than 6 sq. ft in cross sectional area, SDC D, E, or F	1.20	0.00	☐	Retail	Acceleration
D4011.024a	Fire Sprinkler Water Piping - Horizontal Mains and Branches - Old Style Vitaulic - Thin Wall Steel - with designed bracing, SDC D, E, or F (OSHPD or sim), PIPING FRA...	3.90	0.00	☐	Retail	Acceleration
D4011.053a	Fire Sprinkler Drop Standard Threaded Steel - Dropping into braced lay-in tile SOFT ceiling - 6 ft. long drop maximum, SDC D, E, or F	1.73	0.00	☐	Retail	Acceleration
E2022.001	Modular office work stations.	15.00	0.00	☐	Retail	Acceleration
E2022.010	Unsecured fragile objects on shelves, unknown restraint	60.00	0.00	☐	Retail	Acceleration
E2022.023	Desktop electronics including computers, monitors, stereos, etc, smooth surface	15.00	0.00	☐	Retail	Acceleration
E2022.106b	Bookcase, 6 shelves, anchored laterally	30.00	0.00	☐	Retail	Acceleration
E2022.125b	Lateral Filing Cabinet, 4 drawer, anchored laterally	4.00	0.00	☐	Retail	Acceleration
F1012.001	Storage racks designed and installed before 2007, big box retail (12' to 15' tall)	30.00	0.00	☐	Retail	Acceleration

Figure 7.9: Performance Groups specification: floor 1, direction 3. [Source: PACT]



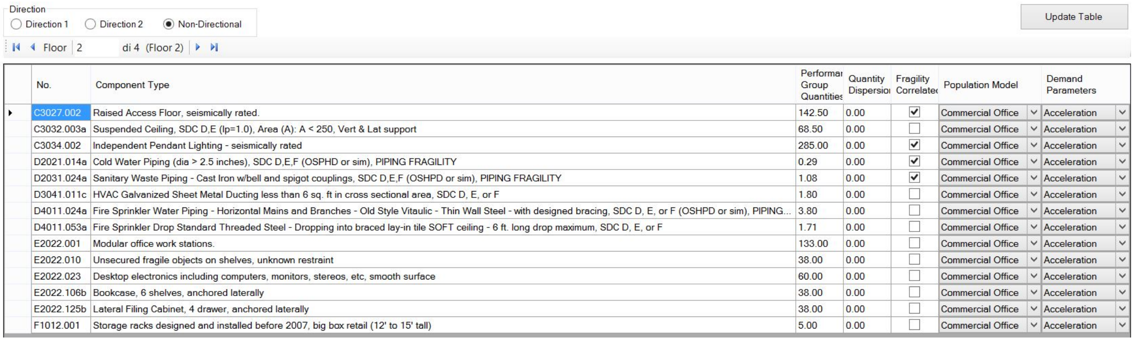
No.	Component Type	Performance Group Quantities	Quantity Dispersion	Fragility Correlated	Population Model	Demand Parameters
B2022.001	Curtain Walls - Generic Midrise Stick-Built Curtain wall, Co...	190.00	0.00	☑	Commercial Office	Story Drift Ratio
C1011.001a	Wall Partition, Type: Gypsum with metal studs, Full Height...	10.00	0.00	☐	Commercial Office	Story Drift Ratio
C1011.001b	Wall Partition, Type: Gypsum with metal studs, Partial Hei...	9.00	0.00	☐	Commercial Office	Story Drift Ratio
C2011.011a	Non-monolithic precast concrete stair assembly with conc...	2.00	0.00	☐	Commercial Office	Story Drift Ratio

Figure 7.10: Performance Groups specification: floor 2, direction 1. [Source: PACT]



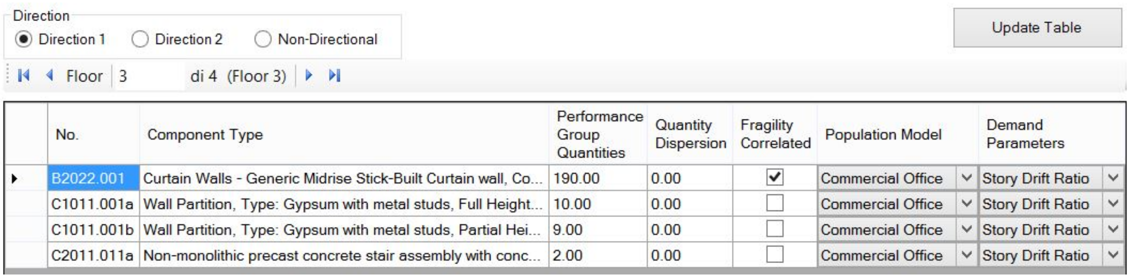
No.	Component Type	Performance Group Quantities	Quantity Dispersion	Fragility Correlated	Population Model	Demand Parameters
B2022.001	Curtain Walls - Generic Midrise Stick-Built Curtain wall, Co...	190.00	0.00	☑	Commercial Office	Story Drift Ratio
C1011.001a	Wall Partition, Type: Gypsum with metal studs, Full Height...	10.00	0.00	☐	Commercial Office	Story Drift Ratio
C1011.001b	Wall Partition, Type: Gypsum with metal studs, Partial Hei...	9.00	0.00	☐	Commercial Office	Story Drift Ratio
C2011.011a	Non-monolithic precast concrete stair assembly with conc...	2.00	0.00	☐	Commercial Office	Story Drift Ratio

Figure 7.11: Performance Groups specification: floor 2, direction 2. [Source: PACT]



No.	Component Type	Performance Group Quantities	Quantity Dispersion	Fragility Correlated	Population Model	Demand Parameters
C3027.002	Raised Access Floor, seismically rated.	142.50	0.00	☑	Commercial Office	Acceleration
C3032.003a	Suspended Ceiling, SDC D,E (Ip=1.0), Area (A): A < 250, Vert & Lat support	68.50	0.00	☐	Commercial Office	Acceleration
C3034.002	Independent Pendant Lighting - seismically rated	285.00	0.00	☑	Commercial Office	Acceleration
D2021.014a	Cold Water Piping (dia > 2.5 inches), SDC D,E,F (OSPHD or sim), PIPING FRAGILITY	0.29	0.00	☑	Commercial Office	Acceleration
D2031.024a	Sanitary Waste Piping - Cast Iron w/bell and spigot couplings, SDC D,E,F (OSHPD or sim), PIPING FRAGILITY	1.08	0.00	☑	Commercial Office	Acceleration
D3041.011c	HVAC Galvanized Sheet Metal Ducting less than 6 sq. ft in cross sectional area, SDC D, E, or F	1.80	0.00	☐	Commercial Office	Acceleration
D4011.024a	Fire Sprinkler Water Piping - Horizontal Mains and Branches - Old Style Vitaulic - Thin Wall Steel - with designed bracing, SDC D, E, or F (OSHPD or sim), PIPING...	3.80	0.00	☐	Commercial Office	Acceleration
D4011.053a	Fire Sprinkler Drop Standard Threaded Steel - Dropping into braced lay-in tile SOFT ceiling - 6 ft. long drop maximum, SDC D, E, or F	1.71	0.00	☐	Commercial Office	Acceleration
E2022.001	Modular office work stations.	133.00	0.00	☐	Commercial Office	Acceleration
E2022.010	Unsecured fragile objects on shelves, unknown restraint	38.00	0.00	☐	Commercial Office	Acceleration
E2022.023	Desktop electronics including computers, monitors, stereos, etc, smooth surface	60.00	0.00	☐	Commercial Office	Acceleration
E2022.106b	Bookcase, 6 shelves, anchored laterally	38.00	0.00	☐	Commercial Office	Acceleration
E2022.125b	Lateral Filing Cabinet, 4 drawer, anchored laterally	38.00	0.00	☐	Commercial Office	Acceleration
F1012.001	Storage racks designed and installed before 2007, big box retail (12' to 15' tall)	5.00	0.00	☐	Commercial Office	Acceleration

Figure 7.12: Performance Groups specification: floor 2, direction 3. [Source: PACT]



No.	Component Type	Performance Group Quantities	Quantity Dispersion	Fragility Correlated	Population Model	Demand Parameters
B2022.001	Curtain Walls - Generic Midrise Stick-Built Curtain wall, Co...	190.00	0.00	☑	Commercial Office	Story Drift Ratio
C1011.001a	Wall Partition, Type: Gypsum with metal studs, Full Height...	10.00	0.00	☐	Commercial Office	Story Drift Ratio
C1011.001b	Wall Partition, Type: Gypsum with metal studs, Partial Hei...	9.00	0.00	☐	Commercial Office	Story Drift Ratio
C2011.011a	Non-monolithic precast concrete stair assembly with conc...	2.00	0.00	☐	Commercial Office	Story Drift Ratio

Figure 7.13: Performance Groups specification: floor 3, direction 1. [Source: PACT]

Direction: ○ Direction 1 ◉ Direction 2 ○ Non-Directional

Update Table

Floor 3 di 4 (Floor 3)

No.	Component Type	Performance Group Quantities	Quantity Dispersion	Fragility Correlated	Population Model	Demand Parameters
B2022.001	Curtain Walls - Generic Midrise Stick-Built Curtain wall, Co...	190.00	0.00	☑	Commercial Office	Story Drift Ratio
C1011.001a	Wall Partition, Type: Gypsum with metal studs, Full Height...	10.00	0.00	☐	Commercial Office	Story Drift Ratio
C1011.001b	Wall Partition, Type: Gypsum with metal studs, Partial Hei...	9.00	0.00	☐	Commercial Office	Story Drift Ratio
C2011.011a	Non-monolithic precast concrete stair assembly with conc...	2.00	0.00	☐	Commercial Office	Story Drift Ratio

Figure 7.14: Performance Groups specification: floor 3, direction 2. [Source: PACT]

Direction: ○ Direction 1 ○ Direction 2 ◉ Non-Directional

Update Table

Floor 3 di 4 (Floor 3)

No.	Component Type	Performance Group Quantities	Quantity Dispersion	Fragility Correlated	Population Model	Demand Parameters
C3027.002	Raised Access Floor, seismically rated.	142.50	0.00	☑	Commercial Office	Acceleration
C3032.003a	Suspended Ceiling, SDC D,E (Ip=1.0), Area (A): A < 250, Vert & Lat support	68.50	0.00	☐	Commercial Office	Acceleration
C3034.002	Independent Pendant Lighting - seismically rated	285.00	0.00	☑	Commercial Office	Acceleration
D2021.014a	Cold Water Piping (dia > 2.5 inches), SDC D,E,F (OSPHD or sim), PIPING FRAGILITY	0.29	0.00	☑	Commercial Office	Acceleration
D2031.024a	Sanitary Waste Piping - Cast Iron w/bell and spigot couplings, SDC D,E,F (OSHPD or sim), PIPING FRAGILITY	1.08	0.00	☑	Commercial Office	Acceleration
D3041.011c	HVAC Galvanized Sheet Metal Ducting less than 6 sq. ft in cross sectional area, SDC D, E, or F	1.80	0.00	☐	Commercial Office	Acceleration
D4011.024a	Fire Sprinkler Water Piping - Horizontal Mains and Branches - Old Style Vitaulic - Thin Wall Steel - with designed bracing, SDC D, E, or F (OSHPD or sim), PIPING...	3.80	0.00	☐	Commercial Office	Acceleration
D4011.053a	Fire Sprinkler Drop Standard Threaded Steel - Dropping into braced lay-in tile SOFT ceiling - 6 ft. long drop maximum, SDC D, E, or F	1.71	0.00	☐	Commercial Office	Acceleration
E2022.001	Modular office work stations.	133.00	0.00	☐	Commercial Office	Acceleration
E2022.010	Unsecured fragile objects on shelves, unknown restraint	38.00	0.00	☐	Commercial Office	Acceleration
E2022.023	Desktop electronics including computers, monitors, stereos, etc, smooth surface	60.00	0.00	☐	Commercial Office	Acceleration
E2022.106b	Bookcase, 6 shelves, anchored laterally	38.00	0.00	☐	Commercial Office	Acceleration
E2022.125b	Lateral Filing Cabinet, 4 drawer, anchored laterally	38.00	0.00	☐	Commercial Office	Acceleration
F1012.001	Storage racks designed and installed before 2007, big box retail (12' to 15' tall)	5.00	0.00	☐	Commercial Office	Acceleration

Figure 7.15: Performance Groups specification: floor 3, direction 3. [Source: PACT]

7.3.5 Collapse Fragility

The Collapse Fragility sheet is used to model structural collapse and its consequences. Collapse fragility is defined in terms of the median spectral acceleration, g, at the fundamental period of structure that can cause structural collapse and the associated dispersion. At least one collapse mode needs to be defined. In addition, the mutually exclusive probability of collapse in each mode conditioned on collapse occurring is also entered. The fraction of each floor affected by a collapse is specified in a table.

In this case study, the collapse dynamic was considered as a total collapse, because of the rupture of seismic isolators and the uncertain phaenomena that can occurr after that rupture. Data have been defined by looking at the *OpenSees* results: collapse has been defined when the story displacement is higher than 4%, so the median acceleration value corresponds to the average of the accelerations in the collapsed demand vectors. Choices are reported in Figure 7.16.

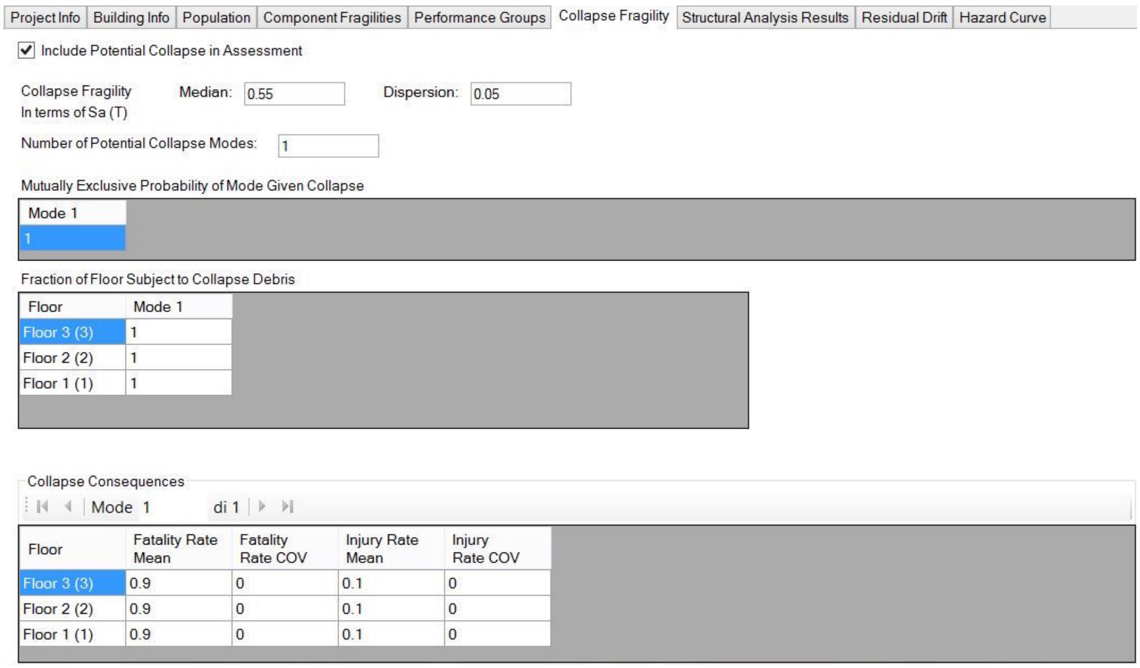


Figure 7.16: Collapse Fragility definition. [Source: PACT]

7.3.6 Structural analysis results

In PACT it is possible to define three types of performance assessment: intensity-based, scenario-based, and time-based assessments.

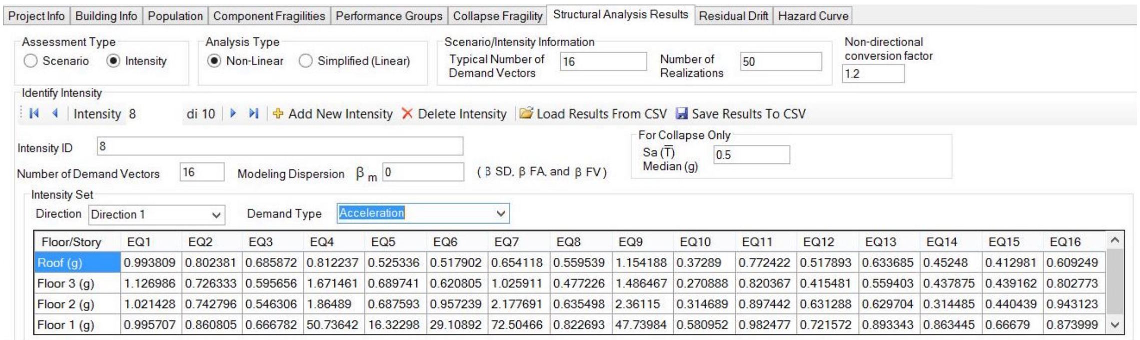
In general, intensity-based assessments evaluate performance for a user-selected acceleration response spectrum, scenario-based assessments evaluate performance for a user-selected earthquake magnitude and time-based assessments evaluate performance over time, considering all possible earthquakes and their probability of occurrence.

This research employed an intensity-based assessment that considered story accelerations and displacements at 8 different intensities that were set from 0.3 to 1.2 times the spectral acceleration at the MCE level. Results have been taken from *OpenSees* outputs. According to the structural model:

- The analysis type was set to "Non-Linear";
- The number of demand vectors was set to 16, that is the number of considered ground motions;
- The number of realizations was set to 50: it is the number of simulations that PACT performs in order to create different possible damage scenarios.

The structure has been simulated by considering the whole earthquake acting only at the worst direction for the structure. PACT requires the use of two directions, so the same results for one direction were put also in the second one and, in order not to get results that are too conservative, the considered damage scenario is an average result among all 50 realizations.

The following Figures 7.17 and 7.18 report the input data of displacements for the MCE level intensity. For all the other 9 intensities, the input data were the same as reported in the *OpenSees* results (Annex D).



Floor/Story	EQ1	EQ2	EQ3	EQ4	EQ5	EQ6	EQ7	EQ8	EQ9	EQ10	EQ11	EQ12	EQ13	EQ14	EQ15	EQ16
Roof (g)	0.993809	0.802381	0.685872	0.812237	0.525336	0.517902	0.654118	0.559539	1.154188	0.37289	0.772422	0.517893	0.633685	0.45248	0.412981	0.609249
Floor 3 (g)	1.126986	0.726333	0.595656	1.671461	0.689741	0.620805	1.025911	0.477226	1.486467	0.270888	0.820367	0.415481	0.559403	0.437875	0.439162	0.802773
Floor 2 (g)	1.021428	0.742796	0.546306	1.86489	0.687593	0.957239	2.177691	0.635498	2.36115	0.314689	0.897442	0.631288	0.629704	0.314485	0.440439	0.943123
Floor 1 (g)	0.995707	0.860805	0.666782	50.73642	16.32298	29.10892	72.50466	0.822693	47.73984	0.580952	0.982477	0.721572	0.893343	0.863445	0.66679	0.873999

Figure 7.17: Accelerations, Intensity 8. [Source: PACT]

7.3.7 Hazard Curve

This section requires as input the values of the Mean Annual Frequence of Exceedance (MAFE curve). PACT requires also maximum and minimum points,

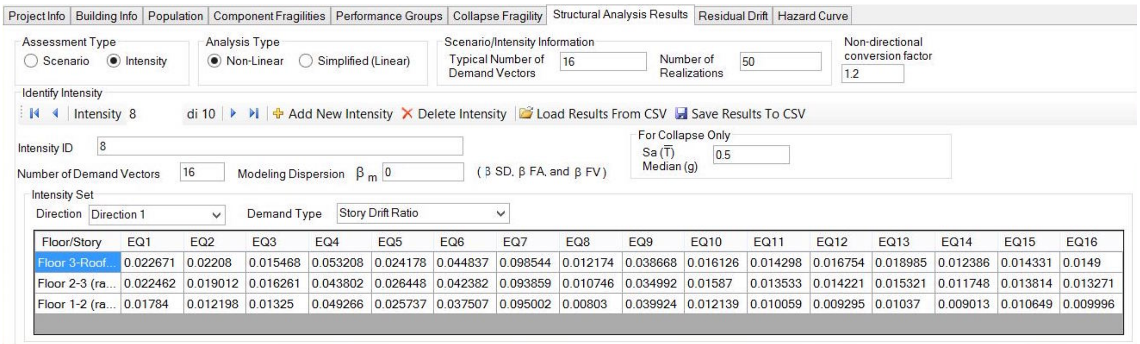


Figure 7.18: Displacements, Intensity 8. [Source: PACT]

that were defined arbitrarily. Figure 7.19 reports the hazard curve definition.

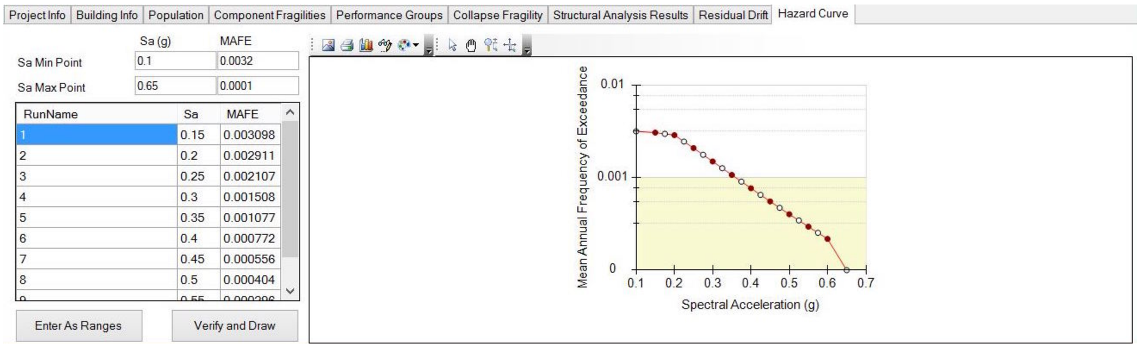


Figure 7.19: Hazard Curve (MAFE). [Source: PACT]

It is necessary to report that a page of the PACT building modeller was not used: that page is the "Residual Drift" data input sheet, that is an optional page to use.

7.4 Damage Scenarios

PACT can give a lot of results from economic losses and restore time to damages and number of injured people. The two following paragraphs describe the results that this research has used:

- *Injured Area*, for defining the amount of injured people for each floor;
- *Damaged Components*, for defining the obstacles in each floor.

The first results were useful for the definition of injured agents in the HPC simulation tool, the second ones were useful for a reliable definition of the environment in the ABM simulation.

7.4.1 Injured Area

PACT results can give the area (in square feet) in which each person who is inside will get injured. The software can define the area that belongs to each non structural component and for each floor. The following tables report the injured area that belongs to each component:

Floor 1 (Retail) at MCE level Values in sq ft			
Direction	Floor	Performance Group	Avg. Injured Area
1	1	B2022.001	74.4
1	1	C1011.001a	0.0
1	1	C1011.001b	0.0
1	1	C2011.011a	0.0
2	1	B2022.001	63.6
2	1	C1011.001a	0.0
2	1	C1011.001b	0.0
2	1	C2011.011a	0.0
3	1	C3027.002	0.0
3	1	C3032.003a	196.8
3	1	C3034.002	0.0
3	1	D2021.014a	0.0
3	1	D2031.024a	0.0
3	1	D3041.011c	0.0
3	1	D4011.024a	0.0
3	1	D4011.053a	0.0
3	1	E2022.001	0.0
3	1	E2022.010	84.3
3	1	E2022.023	21.6
3	1	E2022.106b	0.0
3	1	E2022.125b	0.0
3	1	F1012.001	1500.0

Total (Dir. 1+3)	1877.0
Percentage of injured	8.7%

Floor 2 (Commercial Office) at MCE level Values in sq ft			
Direction	Floor	Performance Group	Avg. Injured Area
1	2	B2022.001	254.3
1	2	C1011.001a	0.0
1	2	C1011.001b	0.0
1	2	C2011.011a	0.0
2	2	B2022.001	347.4
2	2	C1011.001a	0.0
2	2	C1011.001b	0.0
2	2	C2011.011a	0.0
3	2	C3027.002	0.0
3	2	C3032.003a	68.3
3	2	C3034.002	0.0
3	2	D2021.014a	0.0
3	2	D2031.024a	0.0
3	2	D3041.011c	0.0
3	2	D4011.024a	0.0
3	2	D4011.053a	0.0
3	2	E2022.001	0.0
3	2	E2022.010	61.4
3	2	E2022.023	98.8
3	2	E2022.106b	0.0
3	2	E2022.125b	0.0
3	2	F1012.001	300.0

Total (Dir. 2+3)	875.9
Percentage of injured	4.6%

Floor 3 (Commercial Office) at MCE level Values in sq ft			
Direction	Floor	Performance Group	Avg. Injured Area
1	3	B2022.001	297.6
1	3	C1011.001a	0.0
1	3	C1011.001b	0.0
1	3	C2011.011a	0.0
2	3	B2022.001	612.6
2	3	C1011.001a	0.0
2	3	C1011.001b	0.0
2	3	C2011.011a	0.0
3	3	C3027.002	0.0
3	3	C3032.003a	904.5
3	3	C3034.002	0.0
3	3	D2021.014a	0.0
3	3	D2031.024a	0.0
3	3	D3041.011c	0.4
3	3	D4011.024a	0.0
3	3	D4011.053a	0.0
3	3	E2022.001	0.0
3	3	E2022.010	58.9
3	3	E2022.023	97.8
3	3	E2022.106b	0.0
3	3	E2022.125b	0.0
3	3	F1012.001	150.0

Total (Dir. 2+3)	1824.2
Percentage of injured	9.6%

Table 7.2: Injured Areas Results [Extracted from PACT results]

It is possible to see that a lot of components does not show any value. This situation can be caused by two different properties of the model:

- The response of the structure: it is a base-isolated structure, so a lot of components does not present any damage;
- The definition of each component: they are supposed to be built with modern technologies that can prevent critical damages: for example, water and sprinkler pipes are damaged, but they present only leakage at joints and they are not collapsed, so agents are not hurt by them.

These results have been used for defining the percentage of injured people: the research assumes a casual disposition of agents when the earthquake occurs, so the percentage is defined by the ratio between the injured area of each component and the total floor area.

The project also assumes that the 30% of injured people are seriously injured, so they are not able to move until someone helps them. For each floor the percentages of not seriously and seriously injured people are:

- First floor: 6.1% and 2.6% respectively;
- Second floor: 3.2% and 1.4% respectively;
- Third floor: 6.7% and 2.9% respectively.

7.4.2 Damaged Components

PACT results contain the data of the damage state of each component and for each realization. Since PACT analyses are based upon supposed quantities of non structural components, the research has not considered each unit for them, but only the percentage of damaged items upon the their overall values. The previous assumption is taken into an account for each PACT realization and the final result is an average value among all the realizations. Direction-sensible components are considered only in the worst direction. The following Table 7.3 reports the percentages of damaged component:

Floor	Direction	Performance Group	Description	Project value	Multip. Factor	Total	Unit	Damage States	Output value	Total Damaged	Unit	%Damaged	Considerations on damage states	OBSTACLES
1	1	B2022.001	Curtain walls	43.20	30.00	1296.0	sq ft	0 and 1	3.40	102	sq ft	**7.87%**	Glass small cracking	NO
1	1	C1011.001a	Wall partitions	3.00	100.00	300.0	ft	2 and 3	3.00	300	ft	**100.00%**	Bending and gypsum cracking	NO
1	1	C1011.001b	Wall partitions	3.00	100.00	300.0	ft	2 and 3	2.00	200	ft	**66.67%**	Bending and gypsum cracking	NO
1	1	C2011.011a	Precast concrete stairs	2.00	1.00	2.0	each	0	0.00	0	each	**0.00%**	NO DAMAGES	NO
1	3	C3032.003a	Suspendend ceiling	77.76	250.00	19440.0	sq ft	0 and 1	37.00	9250	sq ft	**47.58%**	Only 5% of that area has disodged/fallen tiles	YES
1	3	C3034.002	Independent pendant lighting	324.00	1.00	324.0	each	0 and 1	88.00	88	each	**27.16%**	Disassembly of rods	NO
1	3	D2021.014a	Cold water piping	0.32	1000.00	320.0	ft	0 and 1	0.26	262	ft	**82.00%**	Minor leakage	NO
1	3	D2031.024a	Sanitary waste piping	0.50	1000.00	500.0	ft	0 and 1	0.23	230	ft	**46.00%**	Few joint breaks	NO
1	3	D3041.011c	HVAC ducts	1.20	1000.00	1200.0	ft	0 and 1	0.26	264	ft	**22.00%**	Few sags (No obstacles)	NO
1	3	D4011.024a	Fire Sprinkler Water Piping	3.90	1000.00	3900.0	ft	0 and 1	0.70	702	ft	**18.00%**	Minor leakage	NO
1	3	D4011.053a	Fire Sprinkler Drops	1.73	100.00	173.0	each	0 and 1	0.52	52	each	**30.00%**	Minor leakage	NO
1	3	E2022.001	Modular Office work stations	15.00	1.00	15.0	each	0 and 1	12.00	12	each	**80.00%**	Bent/damaged components	YES
1	3	E2022.010	Unsecured objects on shelves	60.00	1.00	60.0	each	0 and 1	53.00	53	each	**88.33%**	Fallen objects	YES
1	3	E2022.023	Desktop Electronics	15.00	1.00	15.0	each	0 and 1	14.00	14	each	**93.33%**	Fallen elements	YES
1	3	E2022.106b	Bookcases	30.00	1.00	30.0	each	0	0.00	0	each	**0.00%**	NO DAMAGES	NO
1	3	E2022.125b	Lateral Filing Cabinets	4.00	1.00	4.0	each	0	0.00	0	each	**0.00%**	NO DAMAGES	NO
1	3	F1012.001	Storage Racks	30.00	1.00	30.0	each	0 and 1	28.00	28	each	**93.33%**	Debris + 10 fallen	YES
2	2	B2022.001	Curtain walls	190.00	30.00	5700.0	sq ft	0 and 1	38.00	1140	sq ft	**20.00%**	Glass small cracking	NO
2	2	C1011.001a	Wall partitions	10.00	100.00	1000.0	ft	2 and 3	9.60	960	ft	**96.00%**	Bending and gypsum cracking	NO
2	2	C1011.001b	Wall partitions	9.00	100.00	900.0	ft	2 and 3	8.50	850	ft	**94.44%**	Bending and gypsum cracking	NO
2	2	C2011.011a	Precast concrete stairs	2.00	1.00	2.0	each	0	0.00	0	each	**0.00%**	NO DAMAGES	NO
2	3	C3027.002	Raised access floor	142.50	100.00	14250.0	sq ft	0 and 1	31.35	3135	sq ft	**22.00%**	Minor damages	NO
2	3	C3032.003a	Suspendend ceiling	68.50	250.00	17125.0	sq ft	0 and 1	29.20	7300	sq ft	**42.63%**	Only 5% of that area has disodged/fallen tiles	YES
2	3	C3034.002	Independent pendant lighting	285.00	1.00	285.0	each	0 and 1	190.00	190	each	**66.67%**	Disassembly of rods	NO
2	3	D2021.014a	Cold water piping	0.29	1000.00	290.0	ft	0 and 1	0.0638	64	ft	**22.00%**	Minor leakage	NO
2	3	D2031.024a	Sanitary waste piping	1.08	1000.00	1080.0	ft	0 and 1	0.0864	86	ft	**8.00%**	Few joint breaks	NO
2	3	D3041.011c	HVAC ducts	1.80	1000.00	1800.0	ft	0 and 1	0.288	288	ft	**16.00%**	Few sags (No obstacles)	NO
2	3	D4011.024a	Fire Sprinkler Water Piping	3.80	1000.00	3800.0	ft	0 and 1	0.456	456	ft	**12.00%**	Minor leakage	NO
2	3	D4011.053a	Fire Sprinkler Drops	1.71	100.00	171.0	each	0 and 1	0.342	34	each	**20.00%**	Minor leakage	NO
2	3	E2022.001	Modular Office work stations	133.00	1.00	133.0	each	1 and 2	64.00	64	each	**48.12%**	Bent/damaged components	YES
2	3	E2022.010	Unsecured objects on shelves	38.00	1.00	38.0	each	0 and 1	33.00	33	each	**86.84%**	Fallen objects	YES
2	3	E2022.023	Desktop Electronics	60.00	1.00	60.0	each	0 and 1	54.00	54	each	**90.00%**	Fallen elements	YES
2	3	E2022.106b	Bookcases	38.00	1.00	38.0	each	0	0.00	0	each	**0.00%**	NO DAMAGES	NO
2	3	E2022.125b	Lateral Filing Cabinets	38.00	1.00	38.0	each	0	0.00	0	each	**0.00%**	NO DAMAGES	NO
2	3	F1012.001	Storage Racks	5.00	1.00	5.0	each	0 and 1	5.00	5	each	**100.00%**	Debris and 2 fallen	YES
3	2	B2022.001	Curtain walls	190.00	30.00	5700.0	sq ft	1 and 2	57.00	1710	sq ft	**30.00%**	Glass small cracking	NO
3	2	C1011.001a	Wall partitions	10.00	100.00	1000.0	ft	2 and 3	10.00	1000	ft	**100.00%**	Bending and gypsum cracking	NO
3	2	C1011.001b	Wall partitions	9.00	100.00	900.0	ft	2 and 3	7.40	740	ft	**82.22%**	Bending and gypsum cracking	NO
3	2	C2011.011a	Precast concrete stairs	2.00	1.00	2.0	each	0	0.00	0	each	**0.00%**	NO DAMAGES	NO
3	3	C3027.002	Raised access floor	142.50	100.00	14250.0	sq ft	0 and 1	31.50	3150	sq ft	**22.11%**	Minor damages	NO
3	3	C3032.003a	Suspendend ceiling	68.50	250.00	17125.0	sq ft	1 and 2	54.00	13500	sq ft	**78.83%**	Only 5% of that area has disodged/fallen tiles	YES
3	3	C3034.002	Independent pendant lighting	285.00	1.00	285.0	each	1 and 2	222.00	222	each	**77.89%**	Disassembly of rods	NO
3	3	D2021.014a	Cold water piping	0.29	1000.00	290.0	ft	0 and 1	0.02	17	ft	**6.00%**	Minor leakage	NO
3	3	D2031.024a	Sanitary waste piping	1.08	1000.00	1080.0	ft	0 and 1	0.04	43	ft	**4.00%**	Few joint breaks	NO
3	3	D3041.011c	HVAC ducts	1.80	1000.00	1800.0	ft	0 and 1	1.80	1800	ft	**100.00%**	Few sags (No obstacles)	NO
3	3	D4011.024a	Fire Sprinkler Water Piping	3.80	1000.00	3800.0	ft	0 and 1	3.50	3496	ft	**92.00%**	Minor leakage	NO
3	3	D4011.053a	Fire Sprinkler Drops	1.71	100.00	171.0	each	0 and 1	1.71	171	each	**100.00%**	Minor leakage	NO
3	3	E2022.001	Modular Office work stations	133.00	1.00	133.0	each	0 and 1	59.00	59	each	**44.36%**	Bent/damaged components	YES
3	3	E2022.010	Unsecured objects on shelves	38.00	1.00	38.0	each	0 and 1	29.00	29	each	**76.32%**	Fallen objects	YES
3	3	E2022.023	Desktop Electronics	60.00	1.00	60.0	each	0 and 1	55.00	55	each	**91.67%**	Fallen elements	YES
3	3	E2022.106b	Bookcases	38.00	1.00	38.0	each	0	0.00	0	each	**0.00%**	NO DAMAGES	NO
3	3	E2022.125b	Lateral Filing Cabinets	38.00	1.00	38.0	each	0	0.00	0	each	**0.00%**	NO DAMAGES	NO
3	3	F1012.001	Storage Racks	5.00	1.00	5.00	each	0 and 1	4.00	4	each	**80.00%**	Debris, 1 fallen	YES

Table 7.3: Damaged components [Elaborated from PACT results]

7.5 Damage plans

This section describes how PACT damages results have been drawn in the floors plans. Results are available in Appendix E. As said before, PACT assumes average values of the non structural components, so the assumed damaged quantities are a percentage of the total PACT suggested quantities:

- Fallen objects and electronic furnitures are represented in red and they have a thickness of 30 cm.
- Fallen shelves and racks are represented like the previous damages, but they create a thicker obstruction.
- The suspended ceiling has an high percentage of damages, but the definition of the fragility curve says that only the 5% of that amount is dislodged or fallen. The assumption that this research did is that only the 20% of dislodged/fallen tiles creates a real obstacle. These obstructions are represented in orange.

7.6 Starting Value of Confidence Index

Structural analysis results permitted to calibrate the starting value of confidence index for each floor. Takahashi (2010) [54] performed several shaking table tests in which people were put on the machines and they were asked to fill a survey about their degree of anxiety depending on frequency and maximum speed of shaking. The results of the document are linear functions that put in correlation velocity and anxiety level at fixed frequencies. The procedure for moving from structural results to anxiety levels followed the following steps:

- Velocity time history responses were extrapolated from the structural analysis results for each ground motion. Time history responses have been converted to frequency domain responses using fast Fourier transformations in *Matlab*, in order to define frequency domain spectra of velocity. Then the predominant frequencies have been defined for each spectrum by PEER staff;
- Velocities and frequencies have been used for defining Takashi's anxiety levels for each ground motion and for each floor;
- For each floor, the anxiety result is the 90th percentile of the 16 ground motion results;

- Takashi's anxiety level is defined from 0 to 4, so this research used a proportion for defining a confidence index that is defined from 1 to 0 (confidence index has an inverse definition respect to anxiety level);
- The following tables report that the anxiety level is 0.33 for each floor. The corresponding Confidence Index is 0.9175 and the research employes a starting CI equal to 0.9.

Floor 1 (Retail)			
G. M.	Frequency [Hz]	Velocity [m/s]	Anxiety
1	0.195	1.271	0.002
2	0.220	1.007	0.073
3	0.171	2.019	0.012
4	0.146	1.907	0.021
5	0.269	2.333	0.266
6	0.220	1.353	0.074
7	0.244	1.911	0.169
8	0.293	1.067	0.345
9	0.293	1.955	0.357
10	0.366	0.662	0.289
11	0.342	0.874	0.321
12	0.415	0.495	0.229
13	0.366	0.816	0.291
14	0.366	1.132	0.297
15	0.244	0.969	0.017
16	0.232	0.757	0.019
		90^{th} percentile	0.33

Floor 2 (Office)			
G. M.	Frequency [Hz]	Velocity [m/s]	Anxiety
1	0.195	1.271	0.002
2	0.220	1.007	0.073
3	0.171	2.019	0.012
4	0.146	1.907	0.021
5	0.269	2.333	0.266
6	0.220	1.353	0.074
7	0.244	1.911	0.169
8	0.293	1.067	0.345
9	0.293	1.955	0.357
10	0.366	0.662	0.289
11	0.342	0.874	0.321
12	0.415	0.495	0.229
13	0.366	0.816	0.291
14	0.366	1.132	0.297
15	0.244	0.969	0.017
16	0.232	0.757	0.019
		90^{th} percentile	0.33

Floor 3 (Office)			
G. M.	Frequency [Hz]	Velocity [m/s]	Anxiety
1	0.195	1.474	0.002
2	0.220	1.110	0.073
3	0.171	2.153	0.012
4	0.146	2.072	0.022
5	0.269	2.304	0.266
6	0.220	1.317	0.074
7	0.244	2.087	0.170
8	0.293	1.030	0.345
9	0.293	1.947	0.357
10	0.366	0.801	0.291
11	0.342	0.927	0.321
12	0.415	0.646	0.232
13	0.366	0.758	0.290
14	0.366	1.151	0.297
15	0.244	1.130	0.018
16	0.232	0.793	0.019
		90^{th} percentile	0.33

Table 7.4: Anxiety level for each floor

It is possible to make some considerations:

- Takashi's equations are approximated, because he has linearized a non linear behavior that is extrapolated from a 1-to-4 answer;
- The procedure for passing from anxiety level to Confidence Index is not accurate;
- Takashi's document is the only available source for defining a reliable anxiety level, so the starting CI definition can be considered a strong step forward Agent-based simulations even if the results have a high degree of inaccuracies;
- The CI level is acceptable: in fact, even if the intensity of the earthquake is very strong, the base isolation makes long but smooth movements, so the anxiety is reduced compared to a fixed base building.

Chapter 8

Agent-based simulation

This chapter describes the modelization of previous models and scenarios with Repast HPC, an Agent-Based Modeling software, focusing on the assumptions that have been made and on the obtained results.

8.1 Repast HPC

Repast HPC is an ABM simulation tool for high-performance distributed computing platforms, written in C++ and using MPI for parallel operations. MPI means "Message Passing Interface" and it is a library that permits the parallelization of instructions and calculations. Repast HPC is designed for parallel environments where many processes are running in parallel and where the agents themselves are distributed across processes. Shared, synchronized spaces are used for passing an agent from one process over to another, or to gather information such as agent density, blocked exits, etc. from the neighboring processes.

For Civil Engineering applications, parallel computing could be used for models having a huge extension, like a small city. That is the reason why Repast HPC was choosen as the ABM software tool for this project. MPI libraries have been included into the program and the workflow has been automatically splitted among the CPU cores.

8.2 Model Assumptions

8.2.1 Groups and human behavior decisions

In this model, families and groups of friends are considered as the same typology of group. Their definition is done at the beginning of each simulation. Each agent scans the space around him in a radius of 5 cells and if he finds other agents not linked to a group, it creates a group with them.

This scanning procedure is also repeated in each step for defining the following variables:

- The presence or not of members of the agent's group;
- The presence or not of a not seriously injured person;
- The presence or not of a seriously injured person;
- How many agents are around the considered one, in order to define the density of people.

8.2.2 Sight of the emergency exit

The sight of the emergency exit is treated as a probabilistic variable. The probability of seing it depends on how many steps the agent need to make to reach the exit:

- 90% probability if the path has less than 15 steps (4.5 m);
- 50% probability if the path has more than 15 steps, but less than 25 steps;
- 20% probability if the path has more than 25 steps, but less than 50 steps;
- 10% probability if the path has more than 50 steps (15 m);
- 0% probability if the agent decided not to reach the emergency exit (e.g. if it is helping someone);

The human behavior model has high probability values for the search of a missing friend or relative. This project assumes that, after 60 steps (an average evacuation time for three floors, excluding the stairs), the probability of looking for a missing person or following a group is equal to zero. The first aspects is set in order to not have agents casually moving inside the building and the second because following a group is a starting input to give a defined direction to an agent that is behaving as a "follower".

8.2.3 Damage scenarios

As cited before, each floor has been represented as a 181x122 matrix, in which each cell is equivalent to a space of 30x30 cm. Matrices are available in Appendix E. In Repast HPC, each matrix has been converted in a bits grid:

- Cells with value "0" are empty spaces;
- Cells with value "1" are walls and other obstacles;
- Cells with value "2" are the external doors.

8.2.4 Stairs Model

The modelization of the stairs followed these guidelines:

- Slope of 35°;
- The connection of two floors is perfectly guaranteed by two ramps;
- The free width of the stairs is 1.8 m;

In Repast, the width of the stairs has been reduced to 0.9 m. This choice is due because agents can move on all the empty cells: 1.8 m of width means 6 cells. 6 empty cells are able to fit 6 agents, but this is not realistic. The results of all the simulations in the three floors report very few cases in which adjacent cells are occupied by agents, so only the y direction of the stairs has a reduced width. The stairs, using Lee's algorithm only and steps having a huge number of agents evacuating, were affected by the formation of a big crowd in the stairs landings, because the A.I. model was not able to define a free path. This problem has been solved through an additional model, that permitted the agents to move even if an empty path was not possible to be defined.

8.3 Repast HPC outputs

Repast HPC has been programmed in order to give back to the user the following results:

- Comma-separated values file (.csv) of the floor matrices at each simulation step;
- A record file counting how many agents are still in the simulated environment;
- A record file for confirming the used parameters of the human behavior and panic models.

By using the first type of files, it was possible to realize images and frames for video animations and by using the count output it was possible to realize the cumulative curves (including curves for the C.I. calibration). Figure 8.1 show a portion of a frame of the ground floor evacuation. Agents are defined through the blue half-body symbol.

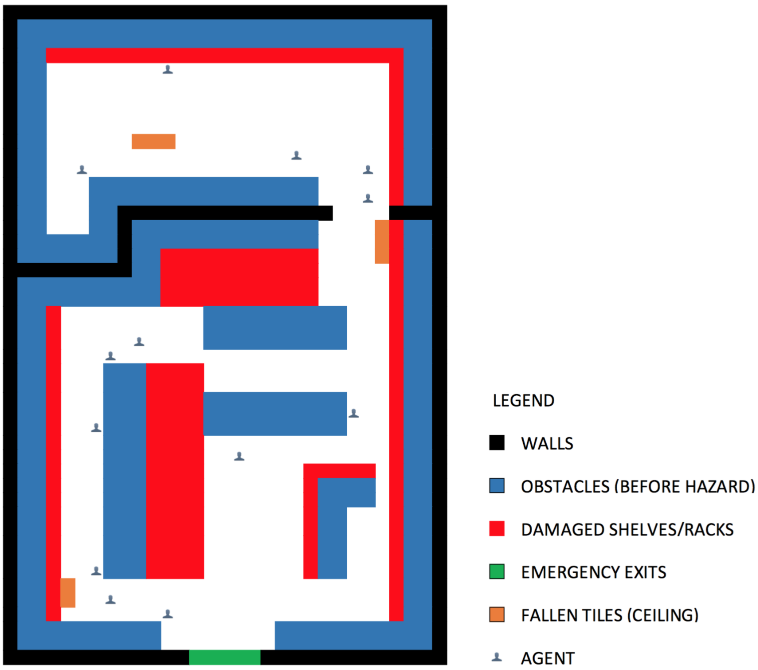


Figure 8.1: Frame of the evacuation

8.4 Confidence Index Calibration

The evacuation time that has been used for the CI calibration is the time that 80% of the agents spend to evacuate the building. CI calibration used two simulations and the following assumptions:

- The first simulation is the evacuation of the ground floor without damages. The population was reduced to 275 agents (75% of the entire floor population) in order not to create a crowded situation;
- The second simulation is the evacuation of the first floor (office). The model has no damages and 140 agents were created, instead of 185;
- For the two office floors, the research used the evacuation time as defined before, plus an addition of the expected time for running through the stairs from each of the considered floors.

8.4.1 First floor

The following graph represents the cumulative distribution of evacuated agents.

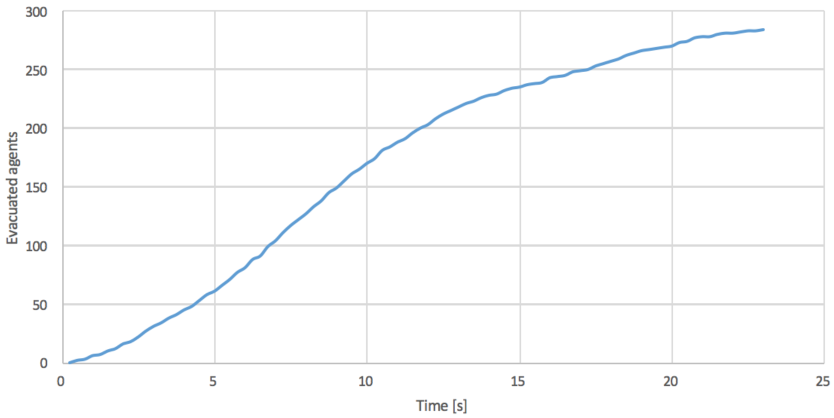


Figure 8.2: Cumulative, ground floor

The evacuation time that is considered for the CI calibration is 14.0 seconds with an incremental value of d_t 0.019.

8.4.2 Second floor

The following graph represents the cumulative distribution of evacuated agents from their starting position to the exit door of their apartment, so those data does not take into account the stairs. The considered time to evacuate the stairs is 24.0 seconds and the floor evacuation time is 25.0 seconds.

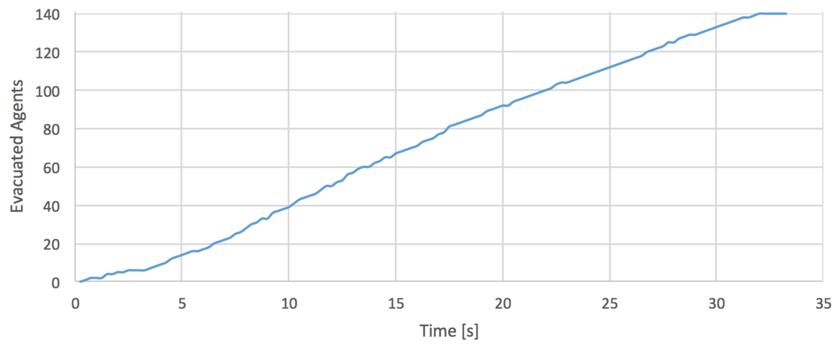


Figure 8.3: Cumulative, second floor

The evacuation time that is considered for the CI calibration is 49.0 seconds and the incremental value of d_t is 0.0054).

8.4.3 Third floor

The CI calibration for the third floor is similar to the previous case. The cumulative distribution is the same of the first floor (Figure 8.3) and the stairs evacuation time is 38 seconds. The evacuation time that is considered for the CI calibration is 63.0 seconds, then the incremental value of d_t is 0.0042.

8.5 Results

This section reports all the cumulative diagrams of the simulations. These are the most important parts of the results of an evacuation simulation, because they let the engineer know how many agents evacuate the building in function of the time. The following diagrams are shown by focusing on the following values of time:

- The total evacuation time, defined as the time that all the agents spend for a complete evacuation;
- The 80^{th} percentile evacuation time, defined as the time spent by the 80% faster agents for leaving the building.

As cited before, sometimes a percentile value of evacuated agents is better than considering the complete evacuation for defining the evacuation time. In particular, highly damaged buildings will report an high number of dead or seriously injured people, so most of them will not evacuate until a rescue team will enter the building: in this case the complete evacuation time can induce to comprehension errors.

Figure 8.4 shows a group formation in a small portion of the second floor. Agents that are gathered in groups are represented through the blue, red and black dots. Alone agents are represented through a blue half-body symbol.

8.5.1 First floor

The cumulative curve for the ground floor is represented in Figure 8.5. 380 agents belong to this floor and the evacuation is completed in 35 seconds. The 80^{th} percentile, 304 agents, completes the evacuation in 25 seconds.

8.5.2 Second and third floors

The evacuation analysis for second and third floor should be done by looking at the cumulative curves of the stairs. 160 agents belong to the left stairs and the evacuation is completed in 104 seconds (1.7 mins ca.). The 80^{th} percentile, 128

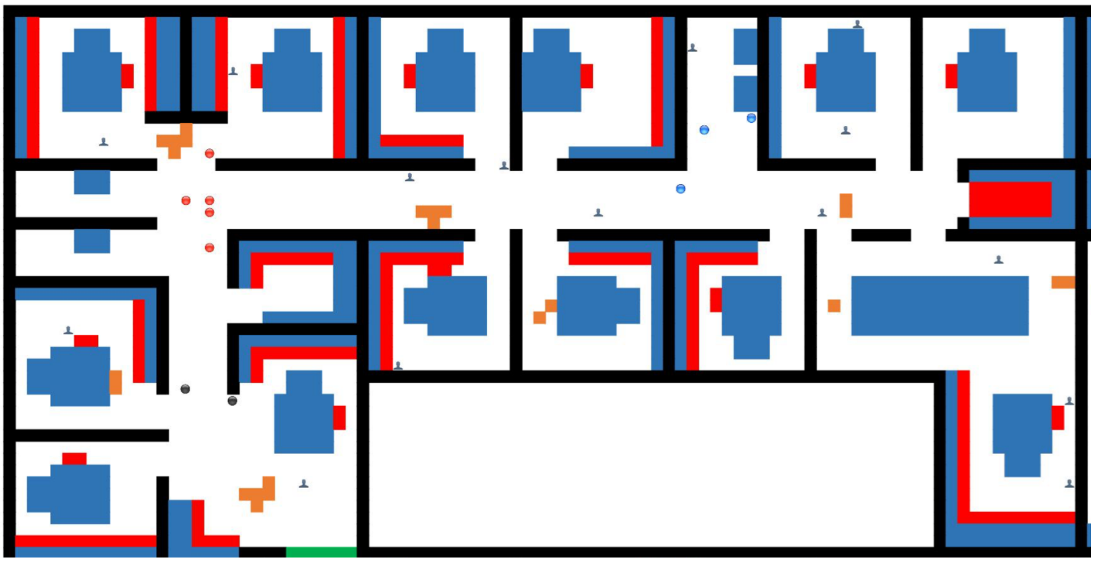


Figure 8.4: Groups in the second floor

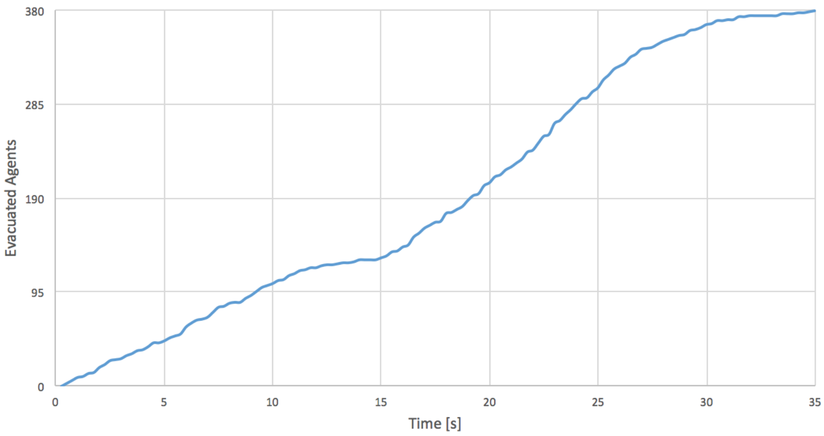


Figure 8.5: Cumulative, Ground floor

agents, evacuates in 88 seconds (1.5 mins ca.). The cumulative curve is reported in Figure 8.6.

210 agents belong to the right stairs and the evacuation lasted 118 seconds (2.0 mins ca.). The 80th percentile, 168 agents, evacuates in 102 seconds (1.7 mins ca.). The cumulative curve is reported in Figure 8.7.

The starting seconds of the simulation are obviously reporting that nobody is evacuating the stairs, because they are supposed to be empty when an earthquake occurs. Figure 8.7 also reports a pleteau between seconds 58 and 66. This behavior is caused by a good amount of people that has just evacuated the building, but at the same time lot of agents are also passing from the floors to the stairs, so there are bottleneck formations in the landings.

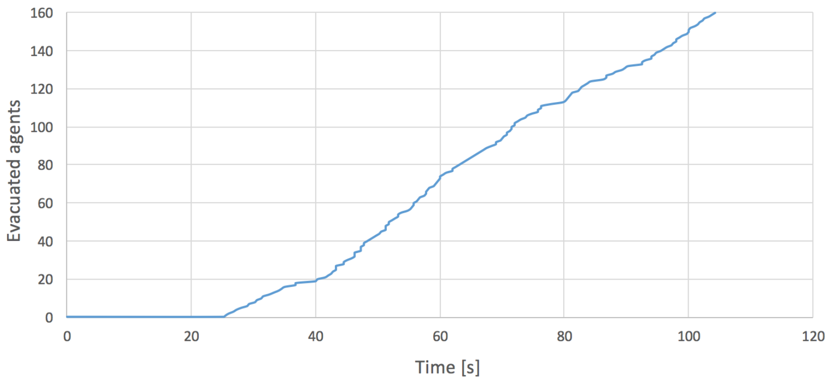


Figure 8.6: Cumulative, Left Stairs

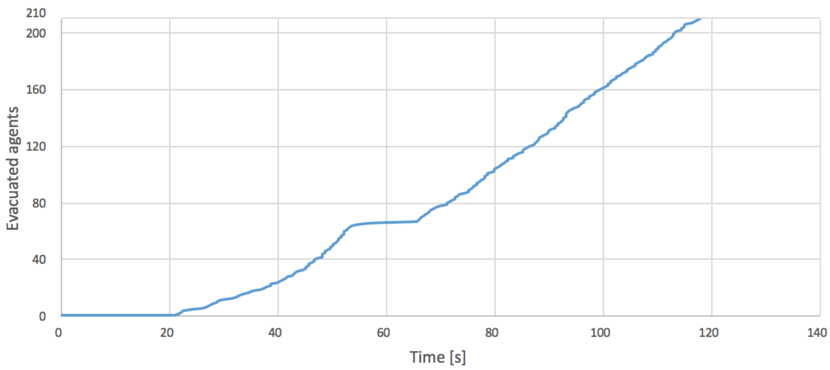


Figure 8.7: Cumulative, Right Stairs

Chapter 9

Sensors-based model

This chapter describes the decisions that have been made for the creation of a reliable sensors based model. Given the importance of all results obtained with regard to the impact of any structural damage to buildings during the evacuation, being able to prevent damage and to continuously analyze the buildings, leads the ABM model to behave almost always with optimal evacuations without the application of damage. In this regard, the research was subsequently focused on the study of a building monitoring technique using sensors equipped with a very high precision digital accelerometer, through which it is possible to detect the natural period of the structure in stationary conditions, thus estimating the possible presence of damage. Always using the sensors, it was possible to compare the data of a building before and after an earthquake, obtaining not only an alarm system, but also a risk modeling technique. This part of research was carried out in collaboration with a San Francisco company called Safehub Inc. and tested in California.

9.1 Introduction

Developing next generation technology to help building owners to be safe, reduce property losses, and monitor structural damages, can helps the community to prevent damage, obtain early warnings and optimal evacuations. Thus, during this research, a self-install inexpensive hardware (the Hub) was built to collects and process data using optimal algorithms, adding the ability to monitor, alert, and provide information services to building owners and insurers through desktop dashboard displays and web notifications, as shown in Figure 9.1.

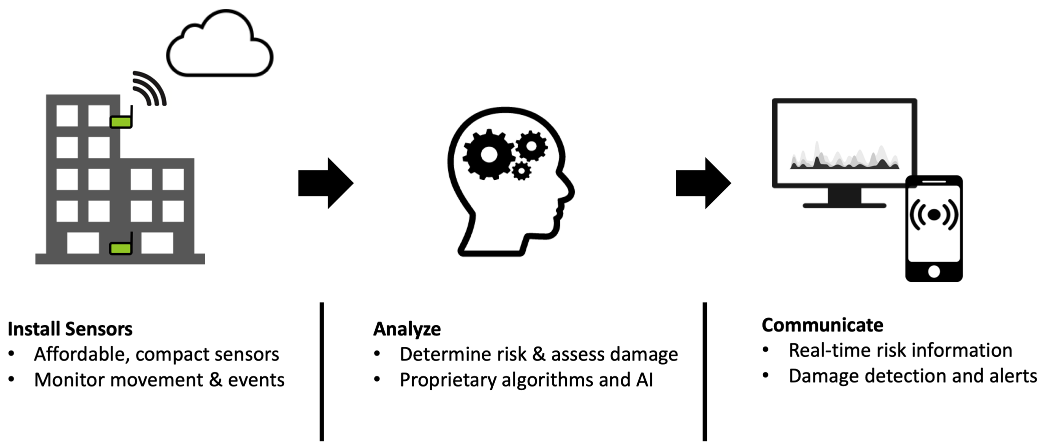


Figure 9.1: How it works

9.2 Technology

The Hub collects and processes acceleration time-history data using a sensitive tri-axis accelerometer and is connected to the internet via cellular network. Raw and/or processed data is sent to a database for alerts, dashboard analytics, and storage. Raw data is also stored locally on the device for approximately 30 days. Access to this local data, firmware updates, and device troubleshooting occur remotely.

The device is directly connected to AC power and includes a battery back-up, preventing the device to loose power and data when a catastrophic event occur.

Sensors are set to be installed in single-family-homes, low-, mid- and high-rise commercial buildings, and industrial facilities, including manufacturing, power, data, and mission-critical. For buildings that are large in plan, complex in behavior, or have multiple stories, groups of sensors can be installed. An overview of the monitoring configuration is shown in Figure 9.2:

For earthquakes, data is processed and analyzed with the following objectives:

- Enhanced risk assessment;
- Damage detection and assessment;
- Early warning.

9.3 Enhanced Risk Assessment

One the main advantages of using building specific sensors is the enhancement of risk assessment by providing information on two key parameters that determine

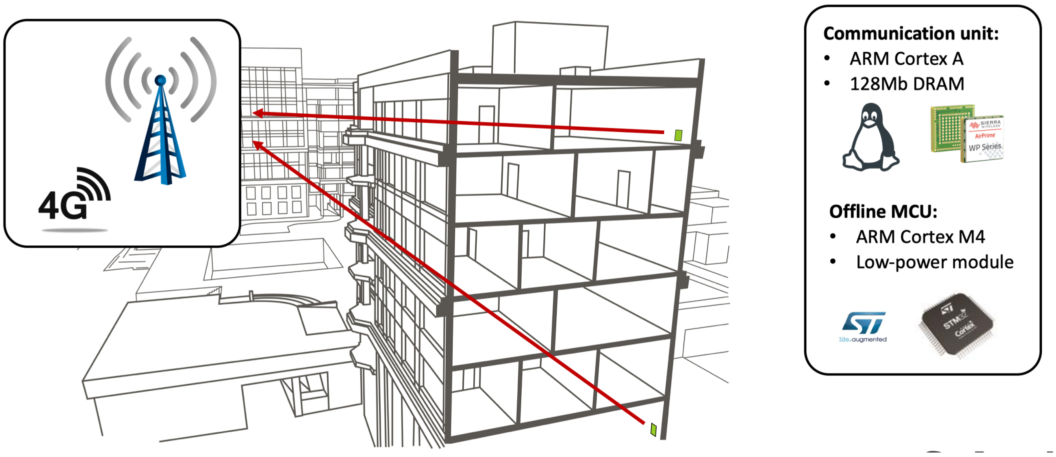


Figure 9.2: Monitoring Configuration

earthquake risk:

- Site-specific soil properties;
- Building dynamic properties.

The idea is to monitor the ambient vibration through the data collected by the Hub to better understand the structural dynamics of each building and detect small or large earthquake events. The data, combined with basic information of the data collected at the time of installation, allow to create a Risk Model that is made available to the users through a web dashboard, as described in the next chapter. Figure 9.3 gives an overview of the process.

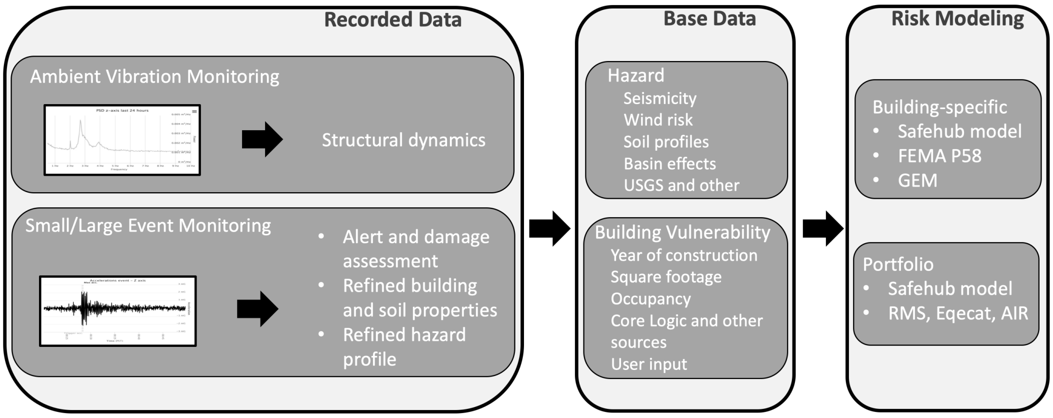


Figure 9.3: Risk Analysis

9.3.1 Site-Specific Soil Properties

How a building resonates with ground excitation is in large part a function of the soil properties (stratigraphy and material properties) supporting and surrounding the building. Soil properties significantly affect site amplification: soft soils will generally increase accelerations locally due to the conservation of energy. Soil properties also significantly impact the dynamic behavior of the combined soil-structure system.

Although there is detailed soil information available for major metropolitan areas of the West Coast of the United States, it is based on the interpretation of large-scale geologic maps that are unable to accurately assess the local variability in soils conditions from site to site. Such maps do not have the ability to assess the variation in soil properties as a function of depth, further limiting the usefulness of these maps. Since earthquake property damage and loss is greatly influenced by soil amplification from earthquakes, accurate soils information will improve earthquake risk assessment. Currently, better estimates can be obtained from in-site geotechnical engineering evaluations, but this is costly and cannot be scaled to multiple sites.

This research methodology for determining site-specific soil properties and associated amplification is cost-effective and scalable. Soil response to ambient vibration (e.g. traffic, ocean waves) and small earthquakes is measured over long periods of time using sensors installed in the lower levels of buildings/homes to approximate free-field response.

Two techniques are then used. The first method is to compare recorded accelerations between sensors in a network, and account for environmental factors, geometric spreading, and source mechanisms. The second method is built to compute horizontal and vertical spectra ratio. HVSR technique is a well-documented method for determining soil properties, typically based on broad-band (expensive) seismometer measurements over short periods of time. With this methodology instead, less-sensitive low-cost accelerometers over long periods of time have been used. Less fidelity in the sensor is offset by the significantly longer measurement periods made possible by having a permanently installed device.

Initial soil properties, including associated amplification, can be obtained in a few weeks with more refined estimates being achieved over time, following small and large earthquakes. If needed for modeling input, Vs30 (average shear-wave velocity to 30m) is back-calculated.

For light structures, the principal effect of the site conditions is amplification. For heavier structures, including mid- and high-rise buildings, and industrial facilities, site conditions affect both site amplification and dynamic response of the soil-structure system and with the proposed technique is possible to provide data in both aspects.

9.3.2 Building Dynamic Properties

Other key properties to estimate how buildings respond during earthquakes are the natural modes and periods of vibration of the structure and/or soil-structure system. These determine how it resonates with the ground motion (affected by soil properties as discussed above), affecting accelerations, forces, and damage during earthquakes. Normally, the first mode in each direction (side-to-side in most buildings) dominates. The effective period (accounting for increased flexibility due to soil and, possibly, damage) for the first mode, is of primary interest to engineers and modelers as this is the assumed period during a large earthquake.

The effective period, Te, is typically estimated using approximate methods based on building height, structural type, and other factors. Most design codes, portfolio catastrophe models, and site-specific risk assessment methodologies incorporate the work of Goel and Chopra (1997) [24], in which instrumented buildings were used to develop upper- and lower-bound estimates for Te. With an approximate 50% variation between bounds, and noting that accelerations and forces are proportional to 1/T for the theoretical elastic behavior for a majority of building stock, significant variability in estimated earthquake response is possible.

The proposed technology determines mode shapes and natural periods directly. Time-domain wave-form data from ambient vibration (e.g. wind) and small earthquakes are converted to the frequency domain, and averaged over long periods of time. Elastic periods are then converted to effective periods for a variety of shaking intensities based on existing numerical relationships and ongoing data collection.

For flexible taller buildings, over approximately 3 stories, mode shapes and periods are estimated after a few days, with more refined estimates being achieved over time, and following small seismic activities. Rare strong earthquakes provide a wealth of valuable information on nonlinear (likely damaged) structural-dynamic properties, including the relationship between elastic and effective periods.

Knowing building vibration periods – and therefore structural stiffness – assists in quantifying the presence and effectiveness of retrofit. Most risk reduction strategies change a structure's stiffness in addition to its strength and ductility.

9.3.3 Effect on Modeled Losses

Results from a preliminary sensitivity study confirm engineering judgment, and show that modelled losses are highly sensitive to changes in assumed properties of the soil-structure system. On a building-specific basis, changing the soil properties by one NEHRP Soil Class (say from D to C) decreases mean loss estimates by up to 50%. Changing the effective natural period from one Goel-and-Chopra bound to another changes loss estimates by up to 40%.

Replacing generic modeling data with more refined data provided by the sensors impacts results, both from mean-loss and uncertainty (tail-risk) perspectives. This impact will be most pronounced for single-building and small-portfolio assessments. This is especially true for highly protected risks, high value facilities, and specialized risks. For very large portfolios, due to the Law of Large Numbers, the most pronounced impact, and of most interest to insurers and reinsurers, will be on tail-risk uncertainty (coefficient of variation) and its significant effect on pure-premium for reinsurance pricing.

Site-specific loss estimates could be affected by up to 40% when sensors data is incorporated, and predicted significant reduction in tail-risk uncertainty.

9.4 Damage Detection and Assessment

Existing methods of damage detection and assessment involve visual inspection by structural engineers or claims adjusters. These are expensive, time consuming, and it is often difficult to see damage on the structure through façades, partitions, and hung ceilings. In cases where intensity maps are used (e.g. USGS ShakeCast), damage estimates are coarse and dependent on the timely release of information.

The proposed methodology (Figure 9.4) provides instead remote and real-time post-event damage assessments using the following methods:

- Correlating sensor readings to vulnerability curves;
- Detecting anomalies and variations in building dynamics.

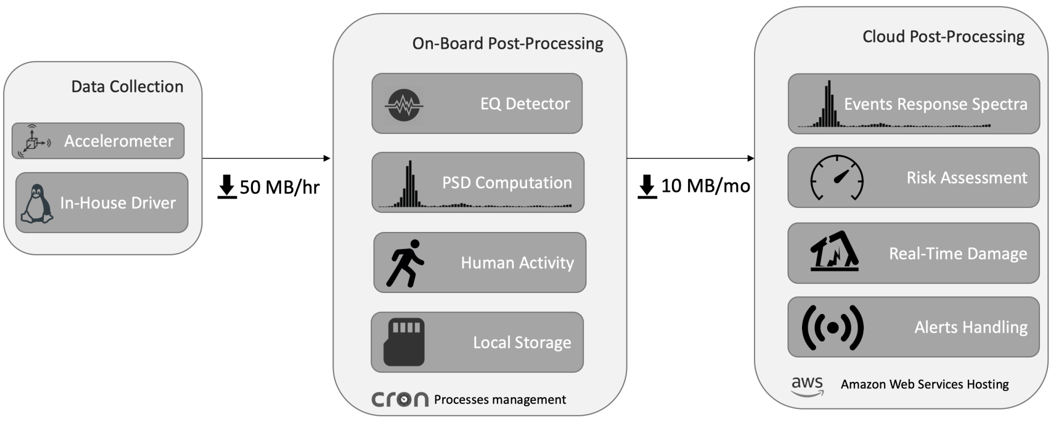


Figure 9.4: Post-Processing

9.4.1 Correlating Sensor Readings to Vulnerability Curves

During earthquake excitation, sensors technology records acceleration time-history wave form data at the base and throughout the building. This data is used to give an overall sense of damage by using the recorded spectral accelerations and calculated displacements as input to the vulnerability curves for the building. This information, provided through dashboard and alerts, increases situational awareness for building owners, insurers, and other stakeholders. This technology is similar to USGS ShakeCast, except that this research uses real-time building-specific data, rather than coarse regional ShakeMap information.

9.4.2 Detecting Anomalies and Variations in Building Dynamics

Another means of estimating damage is to capture changes in building dynamic properties following an event. This could either be through observations in the record itself, or by noting period-elongation due to reduced stiffness of the soil-structure system, which potentially implies that the structure sustained damage.

The intent is not to provide a highly granular assessment of localized damage throughout the building, but more to provide an indication as to overall building damage, and to prioritize buildings that require further investigation by engineers.

There will always be situations where the building will need to be visited by an engineer. This technology will help direct valuable resources, and provide data to the engineer performing an assessment.

9.5 Early Warning

Sensors collects and transmits data that can be used to support earthquake early warning systems, providing typically 20-30 seconds of alert about a damaging earthquake. This will allow people to protect themselves against falling hazards, and for critical equipment to be turned off.

Initially, sensors data are connected to the USGS ShakeAlert system for the West Coast of the United States, this information is then received by the platform and transmitted through loudspeaker in the home, building, or facility. In the future, this technology could develop its own early warning system, beyond the West Coast of the United States.

9.6 Technology Partners and Knowledge Experts

The intent of this research is to create not only world-class scientific and engineering technology, but to ensure that data can be translated into useful and impactful information for building owners, insurers, and other engineering centers.

A primary scientific technology agreement with the California Institute of Technology (Caltech)'s Community Seismic Network was achieved. Through this relationship, access to relevant research and technology with experts in each of the focus areas has already being enstablished.

The results of this research are also being connected with Risk Management Solutions (RMS) to perform sensitivity and ROI studies around the technology; a large Real Estate Investment Trust (REIT) to pilot the technology for industrial facilities; and a major reinsurance company on a substantial residential pilot program. These studies are ongoing.

9.7 Device Specifications

The device primary sensor is a very high-end 3-axis accelerometer. It measures all movements of the Hub (i.e. building movements) with a dynamic range, resolution and sampling rate. Figure 9.5 represents the functional diagram of the device. It is plugged to a standard 5V power adapter. Acceleration data is locally stored at all times on a 32GB microSD card and the device also contains a magnetometer such that the device orientation inside the building can be determined without any user input.

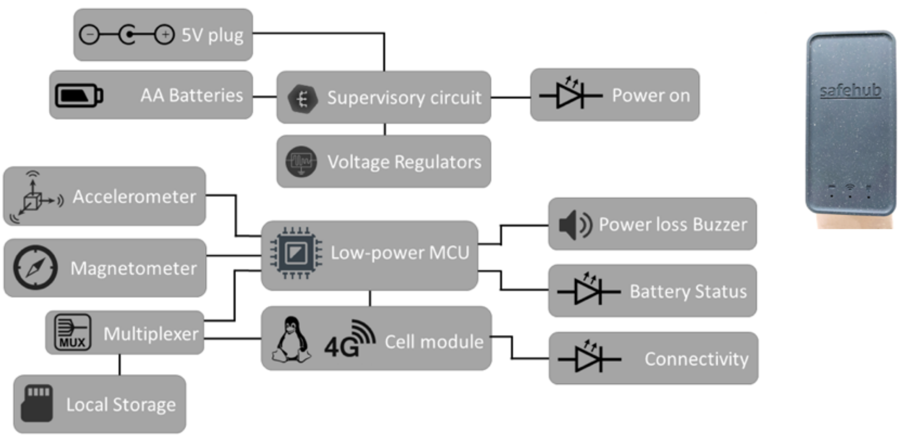


Figure 9.5: Hub Functional Diagram

The device is connected to a dedicated cloud infrastructure via 4G-LTE cat. 4 cellular module as explained in the next subsection. The embedded CPU allows to perform complex operations such as power spectral density computation and event detection. These operations are performed locally primarily to reduce the amount of data transmitted to the cloud infrastructure over the cellular network. In normal operation conditions the device use less than 10MB/month. But in case of an earthquake, the device is able to transmit a very large load of data using high-bandwidth connection. In case of a power outage, the backup batteries take over. A buzzer briefly emits an alarm to warn people in case they accidentally unplugged the device. In this low-power mode, the device shutdowns its cellular connection in order to save power. The data is still stored locally, and if the low-power microcontroller detects an event it briefly wakes up the cellular module to send all relevant data to the cloud. The device is expected to operate for at least two weeks without main power.

9.7.1 Connectivity

Using a cellular connection allow the sensors to be independent from any existing internet configuration in the building and gives an additional layer of reliability in terms of data being safely sent to the cloud even after a catastrophic event has occurred (see Figure 9.6) and, as mentioned above, even if the cellular connection become erratic or missing for a certain amount of time, is still possible to recover the data locally in the device. 4G LTE has been chosen as cellular standard for the proposed Hubs. LTE stands for Long Term Evolution, and is a protocol for wireless high speed data communications which is developed and standardized by the Third Generation Partnership Project, or 3GPP. LTE was originally put forward by Japanese carrier NTT DoCoMo (that at the time of this research is also trying to promote "5G"), and it was only in late 2009 that the first live networks were launched.

"LTE" is a broad term, and the technological foundation will remain for a long time, so in order to differentiate between several LTE evolutions, the industry is using different LTE Categories to describe the LTE network capabilities. There are 11 different categories that are defined, and from a consumer perspective, they mainly differ in terms of theoretical speed. However, an important trade-off of having a greater speed is the use of higher power consumption (Figure 9.7), which is problematic when the electricity goes off and backup batteries overtake to keep the device on. For this reason, the Hub is currently including a Cat. 4 LTE antenna.

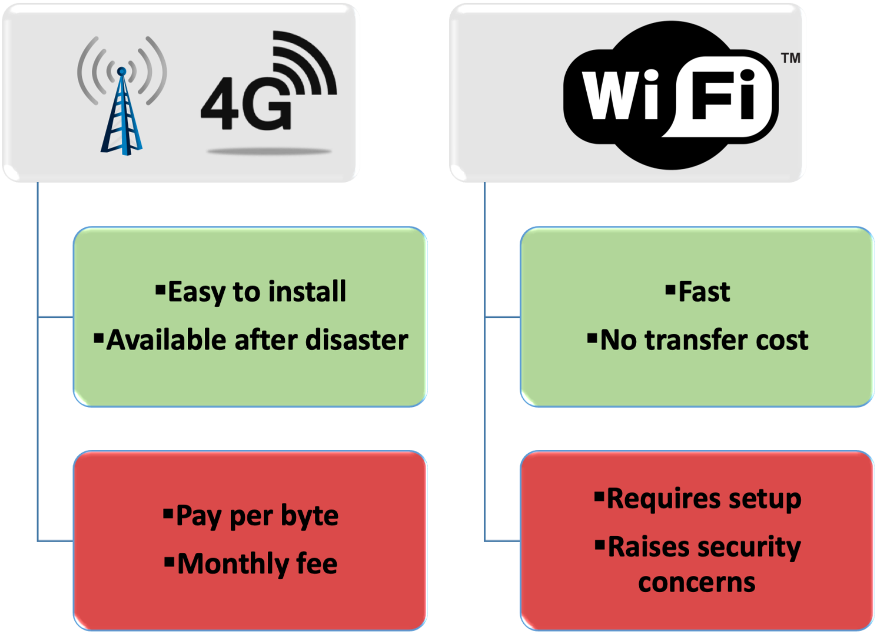


Figure 9.6: Communication

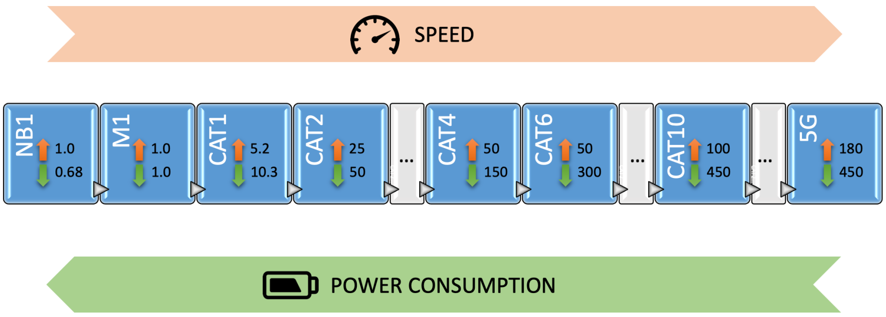


Figure 9.7: LTE Categories

Chapter 10

Web Dashboard

This chapter describes how users can monitor Hub data that has been processed, to allow a visual track of the structural conditions and the risk level associated to an existing portfolio of buildings.

10.1 Introduction

The main purpose of the web dashboard is to provide risk managers and business continuity professionals a sense of knowledge and control of their property risk profile. Currently, the dashboard allows users to obtain building-specific risk information, and an event timeline provides an overview of the buildings affected by earthquakes. The main features provided are the following:

- Portfolio-level risk information, such as AAL, Expected Loss@250yrs,and Key Risk-Drivers;
- A scenario feature to allow users to simulate the performance of their portfolio for a given earthquake (past event or USGS scenario;
- After a catastrophic event, details that instill confidence in results and support engineering teams are provided;
- Highlight the benefits of using sensors in a building.

The platform was built using a web library called React and complemented with database level application interfaces written in Ruby on Rails.

10.2 Portfolio Risk Information

The following Figure 10.1 show how users are able to interact with a pane on the right-hand side to evaluate portfolio risk. The bottom pane is used to display events instead.

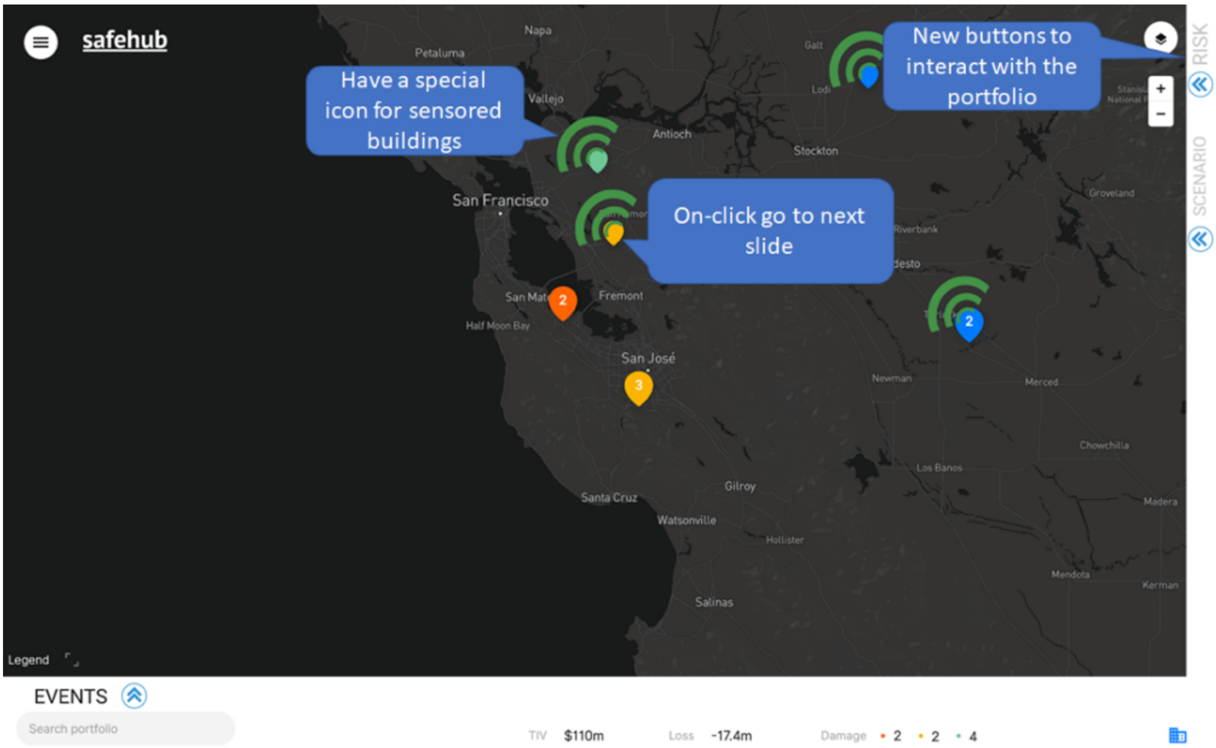


Figure 10.1: Portfolio Page

The portfolio summary page contains information similar to the ones currently displayed on the building page. A plot located at the bottom right of the page lists all the buildings on the x-axis and their average annual loss (AAL) on the y-axis. They are sorted in descending order. The purpose of this plot is to inform the user which buildings are the key risk-drivers in his/her portfolio. Furthermore, as showed in Figure 10.2, the user can navigate on the map to filter the buildings by geography. All the information contained in the "Risk Drivers" box only contains the buildings visible on the map. The Portfolio Event Probability remain static because it is impossible to update this data in real time.

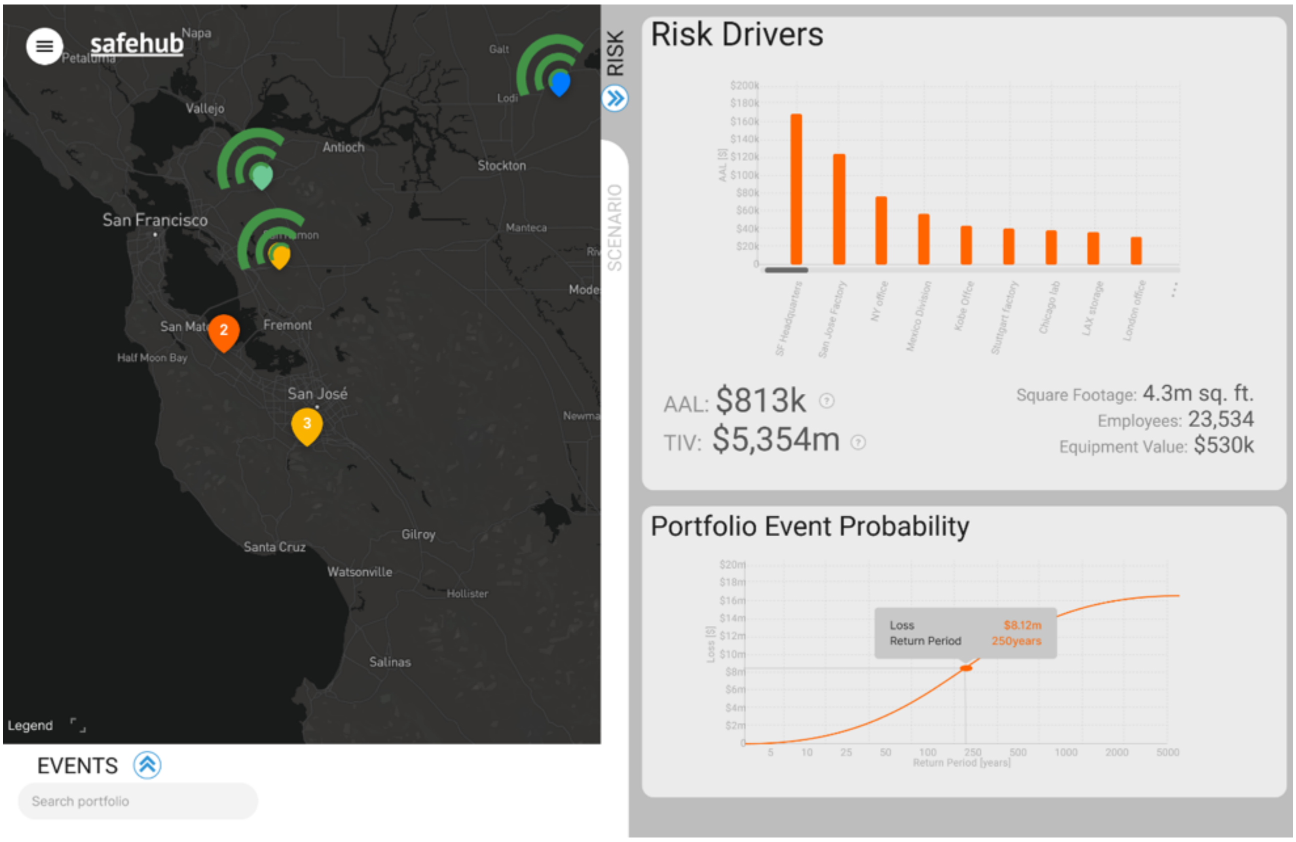


Figure 10.2: Portfolio Risk

10.3 Building Specific Risk Information

In Figure 10.3 and Figure 10.4 it's possible to see how the building page highlight the platform added value. That's why risk metrics are taking a large section of the page. Users are able to display y-axis Loss/Downtime vs. x-axis PGA/Return Period. The color graph represents the expected Building Tag. Its axis can return period or PGA.

10.4 Instrument a Building

Users are notified when buildings in their portfolio are currently not instrumented, to simply remind them to complete the configuration of a device or suggest their adoption and highlight the status of the building itself (see Figure 10.5 and Figure 10.6).

Once the ambient vibration analysis is over and loss estimate has been updated,

Figure 10.3: Building Page - Loss vs. Return Period

the sensor status icon turns green in the website. Also, each user can decide to include/exclude sensor data in their loss estimation (Figure 10.7).

Another important aspect of the platform is the possibility to notify users about seismic activities that affected their portfolio of buildings. Upon logging in, a message informs them when a building was affected by an earthquake and allow them to click on the events pane, which is described in the next section.

10.5 Building Response After an Event

The dashboard displays a list of events related to a building based on USGS data and a list of sensors events that are subsequently divided in two types of sensors events:

- Device event, when the acceleration exceeds a certain threshold, a device will write to a DevicesEvents table in the database. It will only send the time when the event started and ended and are never displayed on the website;

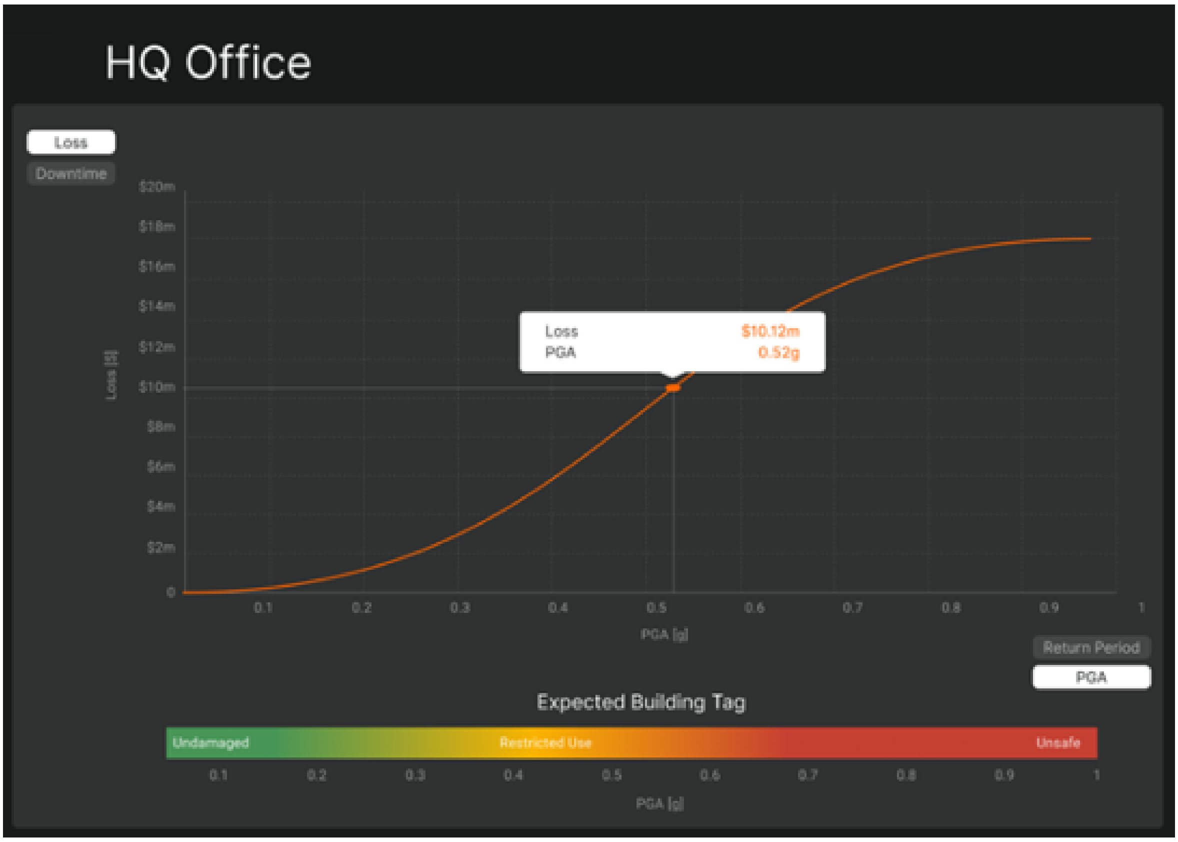


Figure 10.4: Building Page - Loss vs. PGA

- Building event, which are created when 2 or more devices send a device event. This building event forces all devices within a building to upload accelerations data to the cloud and apply a subsequent artificial intelligence algorithm to compute Response Spectra of the signal, displacement, peak ground acceleration, peak ground velocity and MMI.

10.5.1 Buildings Events on the website building page

Currently buildings events are displayed together with USGS events fetched from USGS application interface in a separate "Building page" (Figure 10.8). They are differentiated by a different icon.

The Events list on the Building page displays:

- Date;
- Magnitude;

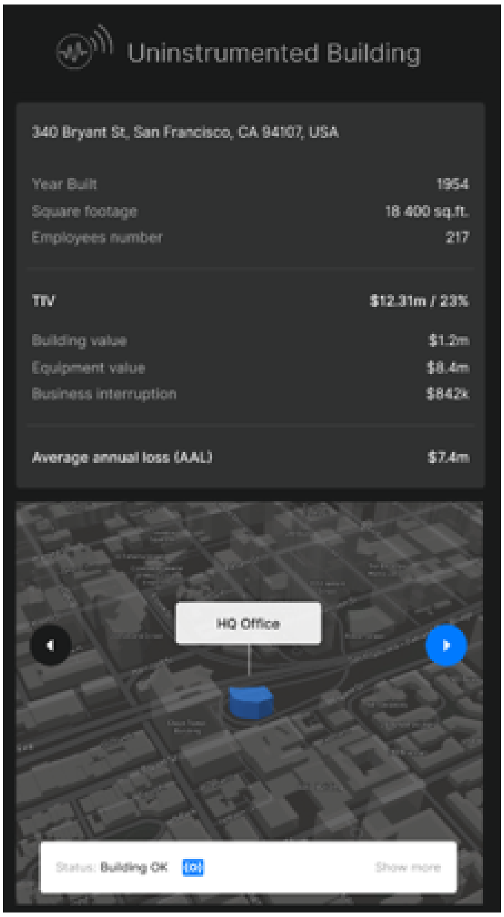


Figure 10.5: Uninstrumented Building

- MMI;
- Estimated Damage.

It is impossible to compute the Magnitude for a Building Event, so the field is left blank for this type of event (N/A or "-"). All the other fields are obtained from the database and a web API fetch all the record that are not older than one year. But when a Building Event occurs, some information are not made available immediately. MMI and Estimated Damage can only be obtained once the data requested by a device event is fully uploaded to the cloud. So if the PGA key is not available, the web interface display "Data is Being Uploaded" in the Estimated Damage column. Once the data is uploaded instead, the PGA key is assigned with a value. Only then a "View Details" button becomes visible in each element of the list. Useful information is also displayed in the form of "Event probability" curve, where loss and MMI are estimated in relation to return period and loss estimate

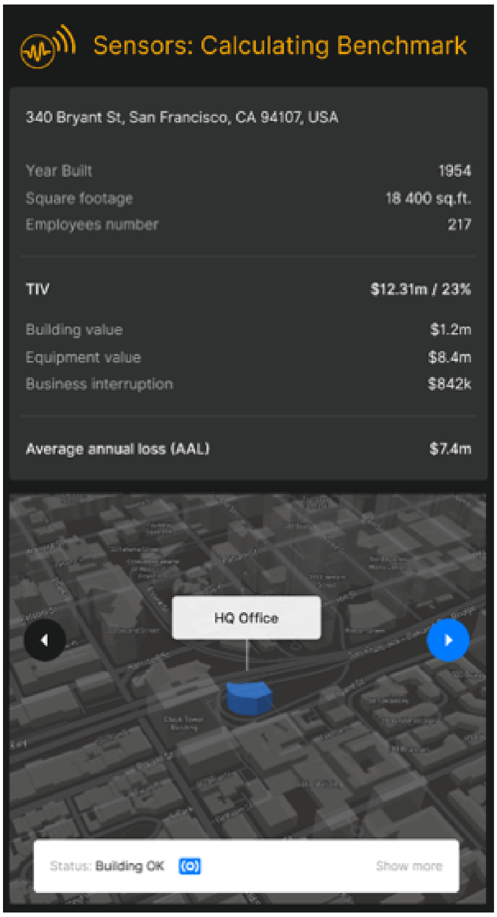


Figure 10.6: Calculating Benchmark

in US dollars. This gives to each user the ability to overview a potential trend of events that could lead to a certain amount of damage and losses, therefore risks, over the course of time. Finally, location of the building inside a tri-dimensional map, together with a summary of information related to it and the average annual loss (AAL) are displayed on the left side of this web page.

10.5.2 Event Details page

As mentioned in the previous section, once all devices in a building finish to upload their accelerations data for further processing, the user is allowed to click on the "View Details" button, which opens up the Events Details page. The list of sensors available in the given building is being listed in a dropdown menu, as shown in Figure 10.9. The list of sensors is fetched from the database by matching building and each device is expected to be physically installed in different stories,

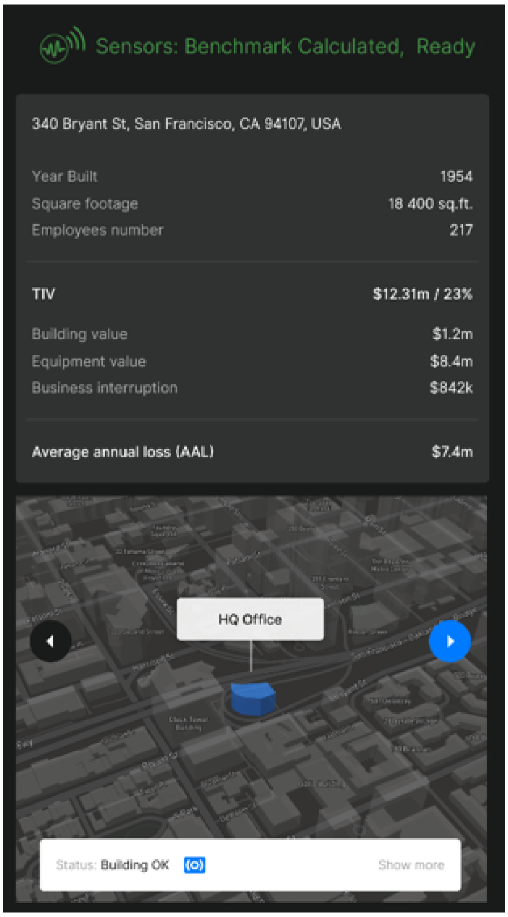


Figure 10.7: Benchmark Calculated

starting from the ground floor.

On the left side of the page, a small simulation of the current shaking is represented, to give users an overall view of the building motion. Then, in the middle, two charts containing the accelerations data uploaded by ground floor device and one of the upper floors devices are displayed, with the possibility to choose the axis being given. The top and bottom plots are identical, but it is useful for the user to display two sensors data simultaneously (for instance ground sensor and third floor). Finally, on the right side, it's possible to view the response spectra of the event. The plot represent two traces, computed with a 2% and 5% damping ratio. The sensor axis displayed correspond to the axis chosen by the user. Right below the response spectra, another plot containing the relative displacement is showed. This gives the user a great understanding of the building motion during the event, especially when associated with the shaking simulation in the same page. Displacements are meaningful only when they are compared with the displacement of

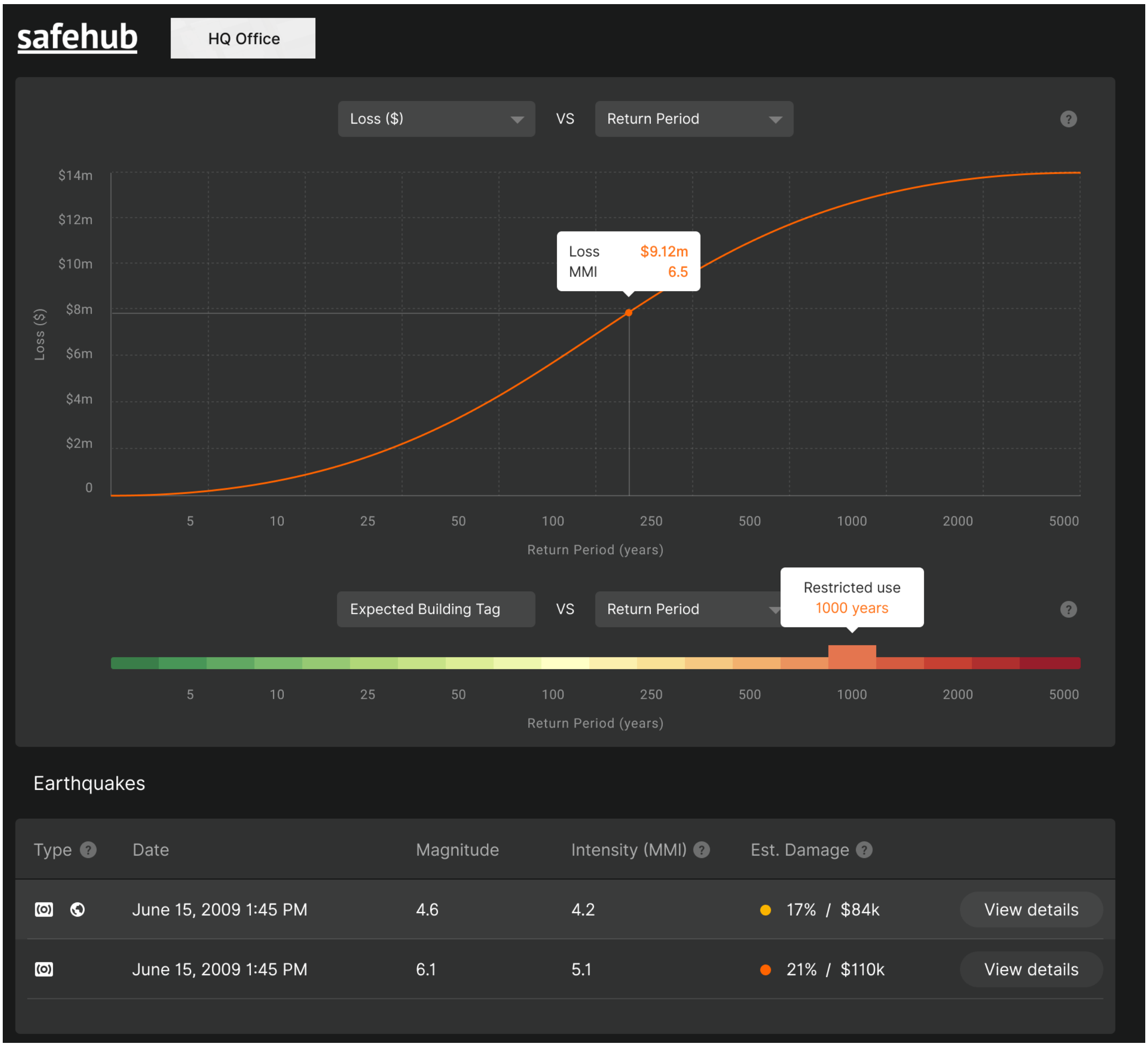


Figure 10.8: Building page with list of events

the ground sensor. For this reason the list contains all sensors except "Ground". All these data is computed by applying refinements to state of the art algorithms provided by mathematical libraries of the C++ programming language and are being run automatically in the cloud.

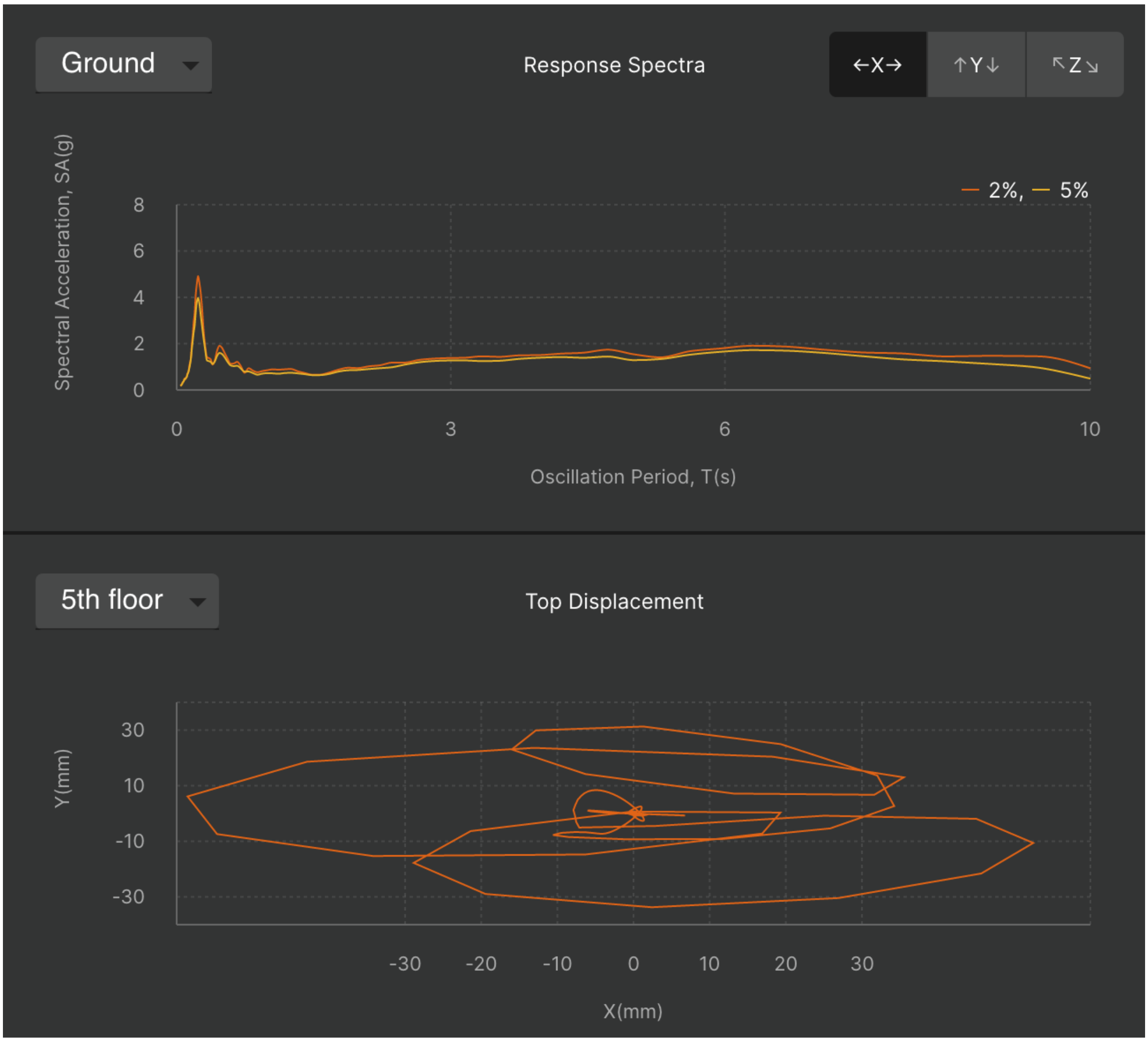


Figure 10.9: Events Page - Sensors data has been processed

10.6 Structural Damage Detection by Power Spectral Density

Early detection of defects in civil structures is a critical process in assisting structural maintenance and management plans. With the platform proposed by this research activity, and its robust damage detection methodology, it becomes possible to repair the structure during early stages of damage. Many damage detection methods require information about the baseline data and the input data. However, the data collection is not always practical because it cannot be readily obtained. Output-only methods use only the vibration response signals and may be classified into nonparametric methods based on corresponding time series representations and methodologies based on scalar or vector parametric time series representations. Power spectral density (PSD), defined as the squared value of the signal, describes the power of a signal or time series distributed over different frequencies. The PSD is the Fourier transform of the autocorrelation function, which provides the transformation from the time-domain to the frequency-domain. From the sensitivities of PSD with respect to the structural damage parameters and finite element model updating, Chen et al. (2014) [26] presented a method to identify buildings damage. Zheng et al. (2014) [67] considered a structural damage detection method from the finite element model, which is updated using the measured PSD. In order to compute PSDs in this platform, the Welch methodology (1967) [42] has been used. The Welch method is used to find the PSD of a signal and to reduce the effect of noise. It divides the time series data into segments, computes a modified periodogram of each segment, and averages the Power Spectral Density Estimation (PSE). A portion of the data stream near the boundaries of the window function is ignored in the analysis, and its situation can be improved by letting the segments overlap. The PSD represents the strength of the variations as a function of frequency. The spectral density characterizes the frequency content of the signal and its estimation detects any periodicities in the data, by observing peaks at the frequencies corresponding to these periodicities. Fang and Perera (2009) [18] introduced power mode shape curvature and power flexibility, and they proposed the damage detection method using their variation between undamaged and damaged states. Variations to the periodicities of the signal in low noise conditions are strong symptoms of structural damage. Users can visualize the PSDs of each building from the building page of the dashboard. Welch method with a frame duration of 30 seconds and an overlap factor of 20% has been used to generate 2800 PSDs each day that are being averaged to each other to finally generate a single PSD every day. In the platform is possible to further compare each daily generated PSD with a PSD of another day, in order to get an overview of the differences and be notified about structural damages detected through the algorithm, as showed in Figure 10.10.

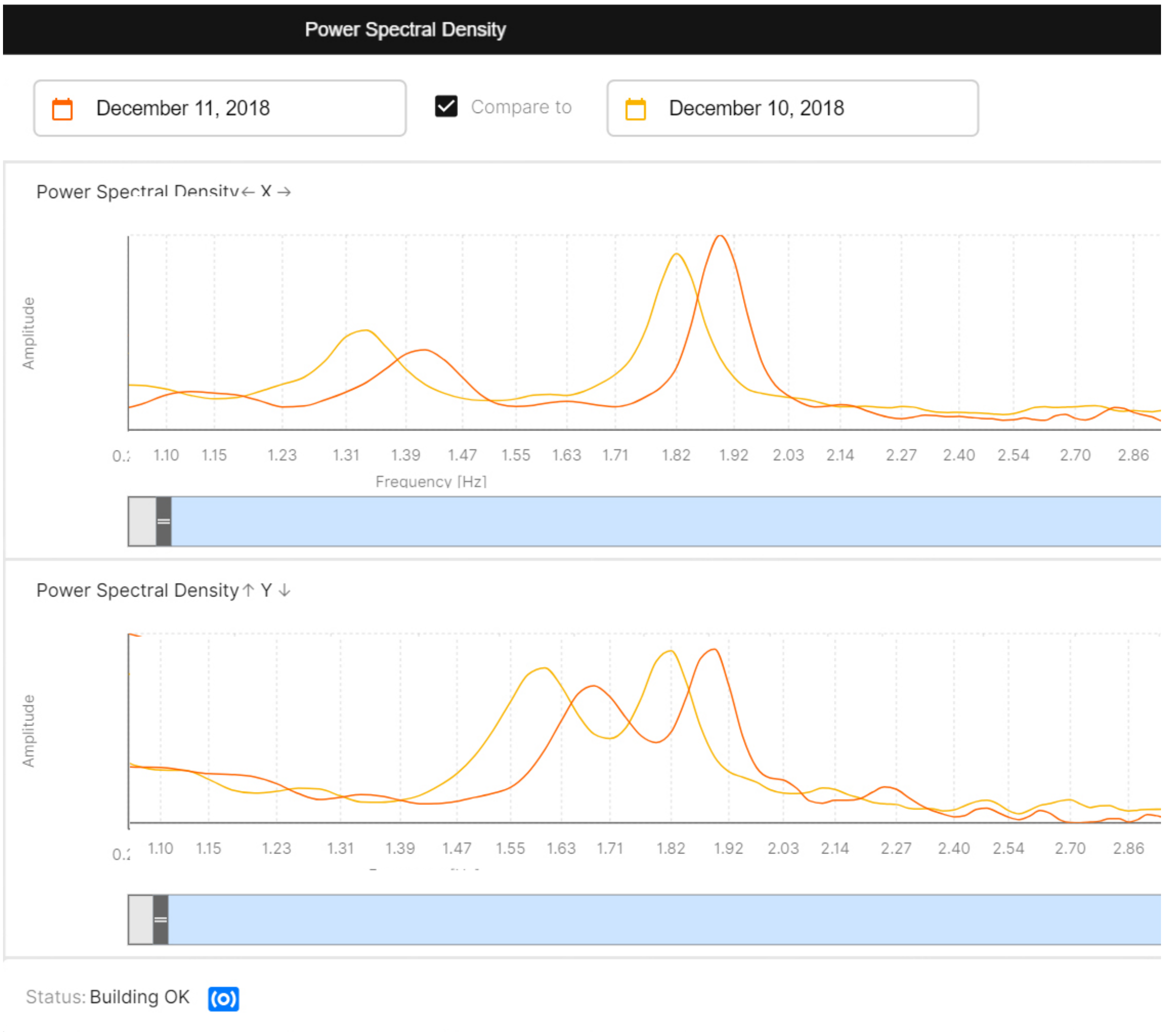


Figure 10.10: PSD Page - PSDs comparison in detected damages

Chapter 11

Conclusions

In Chapters 4–8, the research described several fundamental parts of human behavior and its application to a real evacuation model in catastrophe situations. The reasoning process of human beings was first associated to the Belief Desires and Intentions model, then a panic model with the application of the Decision Field Theory was applied and complemented with a questionnaire-based data collection. This analytic approach additionally allowed us to exhibit several new relations between learning theory, communication complexity and how human behavior affects building evacuations. Panic and human behavior models have given the agents a huge decisional capacity. The case study of a 3 story buildings in Oakland, California, was then used as first practical application of the simulation. This building was firstly tested without considering damage, then by considering it. Damage scenarios creates new obstacles respect to the undamaged structure, so it was proven that the agents needs to find different solutions for escaping the building. The models were implemented using Repast HPC, a parallel computing framework for Agent-Based Modeling. It was proven to be very efficient for large scale buildings due to its parallel computing support and allowed the research to perform high-density populations simulations. To effectively represent damage and risk associated to city models, a portfolio sensors-based approach was then explained in chapters 9-10. The idea was to provide structural health monitoring to every building and portfolio in order create a platform that allows to have a clear view of the damages and risks associated to each building of a city or an entire portfolio. Real-time vulnerability curves, power spectral density comparisons and events based analysis were implemented and provided. This approach has proven to allow monitoring for the risk associated to the structures and therefore improve the precisions and the assumptions taken in the first part of the research, making the model to effectively reflect real life scenarios. The proposed virtual model is applicable to every city, region, State or even Country to give a precise insight of damage levels, risks and evacuation times not only in case of emergencies but also before and after catastrophic events.

11.1 Comments on the results

An overall comment related to this work is the high increase of reliability of simulations, especially when integrated with building specific sensors. That is due because:

- Damage scenarios create new obstacles respect to the undamaged structure, so the agents will need to find different solutions for escaping the building;
- Parallel computing permitted to increase the number of items in the map matrices. Consequently, the number of steps per second increased respect to similar simulations in this field;
- Panic and human behavior models have given the agents a huge decisional capacity, in order to simulate their behavior during the emergency at best.

A demonstration of all these positive improvements is the graph reported in Figure 11.1 cumulative curves for the evacuation of ground floors are reported:

- The blue curve is the cumulative of the building evacuation with only the Lee's model for Artificial Intelligence, without damages, human behavior or panic models;
- The orange curve is the real cumulative curve of this research.

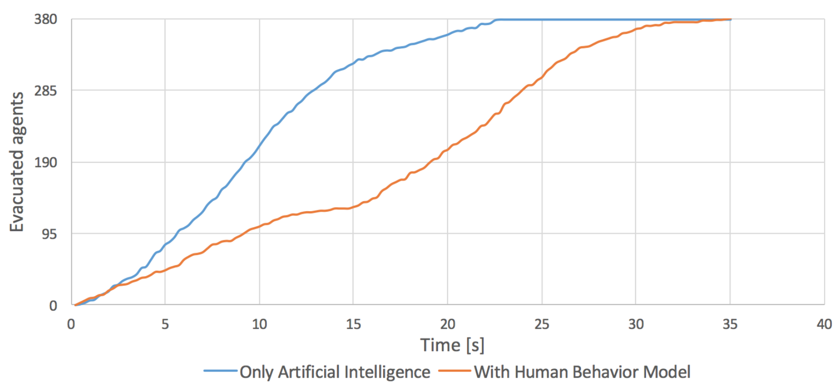


Figure 11.1: Cumulatives of the two models

The analysis of these curves reports that:

- With the "traditional" model with only Artificial Intelligence, the evacuation time (80^{th} percentile) is 14.0 seconds;
- With the model proposed in this research, the evacuation time (80^{th} percentile) is 25.0 seconds.

In this research other simulations have been made in order to make a comparison between the simulations with Artificial Intelligence only and the improved results of this work. The graph in Figure 11.2 reports the distribution of the evacuation time for the ground floor in case of reduced amounts of evacuees. Data report the 80^{th} percentile of evacuation time for each case. The curves are linear tendences that fit the evacuation time of:

- 20% of the entire population, equal to 76 agents (80^{th} percentile corresponds to 61 agents)
- 40%, equal to 152 agents (80^{th} percentile corresponds to 122 agents)
- 60%, equal to 228 agents (80^{th} percentile corresponds to 182 agents)
- 80%, equal to 304 agents (80^{th} percentile corresponds to 243 agents)
- 100%, that is the considered simulation of this research.

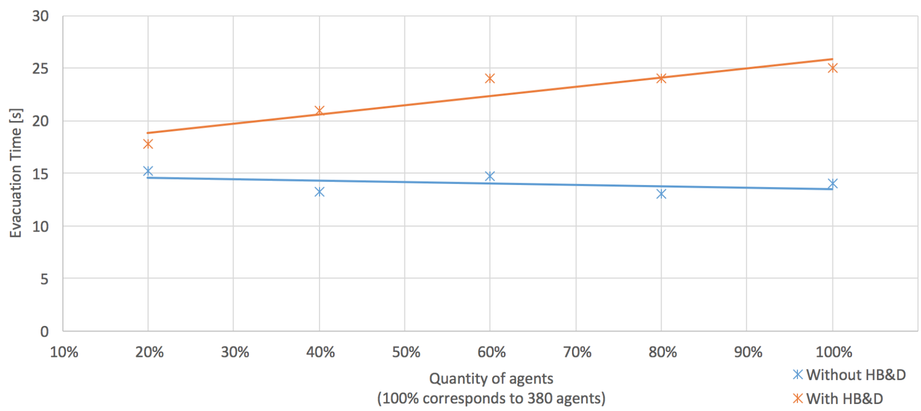


Figure 11.2: Comparison between two Agent-Based models

By observing the curve of an A.I. model, it is possible to confirm that no crowds or bottlenecks are present, because the evacuation time remains constant even if the number of evacuees grows. The curve for refined model reports a significant increase of evacuation time: that is due because with the new models agents can interact better among them and with the damaged environment. If the population increases, more groups are formed and more people get injured, so each agent can be confused and spend more time in helping or finding someone: that is the real reason of the constant increase of evacuation time in these simulations.

Even if some improvements can be done to continuously increase the reliability and to get a better visualization of the results, this work needed the integration of a reliable sensors based model first.

Throughout the use of sensors equipped with a very high precision digital accelerometer that allow to monitor structural damages before and after catastrophic events and the ability to create an enhanced risk assessment web platform, an higher probability to obtain a simplified ABM model with limited damages has been proved. In fact, this research showed how the presence of damage drastically affect the speed of a simulation. Furthermore, providing a web platform to building owners, greatly improve their awareness about seismic activities and related damages, which could be very helpful in areas at risk. Seismic risks are, in fact, determined not only by hazard levels but also by the amount of people and property that are exposed to the hazards and by how vulnerable people and property are to the hazards.

11.2 Future improvements

11.2.1 Panic model

An improvement should be done to the panic model calibration, particularly in the definition of the starting value of confidence index. In Takashi's results the density of points in the velocity-frequency interval of the considered structure is not very high. Consequently, future works should improve the way the starting value of confidence index is defined, through new experiments or data collections made in real cases.

11.2.2 Parallel computing usage

In this research parallel computing was used in order to increase reliability and speed of the simulations on a standard laptop. MPI libraries divided the processes among all the cores in order to simulate each floor and stair ramp separately. A suggestion for future research is to simulate similar structures on a supercomputer: that will mean using MPI libraries also to simulate different floors (or stairs) in parallel to analyze the interdependencies between floors and stairs. This will result in a better analysis of the crowd and all the possible bottlenecks formations.

11.2.3 Early warning timing

Another improvement might be necessary to the early warning system provided by the sensors. Refining the model with algorithms that would allow seismic activities to be predicted even quicker could make such system a revolutionary and portable security alert, for example with the implementation of a dedicated mobile app that could send push notifications to the users.

Bibliography

[1] Icek Ajzen. “The theory of planned behavior”. In: *Organizational behavior and human decision processes* 50.2 (1991), pp. 179–211. ISSN: 0749-5978.

[2] John R Anderson and Jonathan Betz. “A hybrid model of categorization”. In: *Psychonomic Bulletin and Review* 8.4 (2001), pp. 629–647. ISSN: 1069-9384.

[3] Robert Axelrod and William Donald Hamilton. “The evolution of cooperation”. In: *Science* 211.4489 (1981), pp. 1390–1396. ISSN: 0036-8075.

[4] Robert Axelrod and Leigh Tesfatsion. “Appendix AA Guide for Newcomers to Agent-Based Modeling in the Social Sciences”. In: *Handbook of computational economics* 2 (2006), pp. 1647–1659. ISSN: 1574-0021.

[5] Paolo Bellavista et al. “Scalable and Cost-Effective Assignment of Mobile Crowdsensing Tasks Based on Profiling Trends and Prediction: The ParticipAct Living Lab Experience”. In: *Sensors* 15.8 (2015), pp. 18613–18640. ISSN: 1424-8220.

[6] Eric Bonabeau. “Agent-based modeling: Methods and techniques for simulating human systems”. In: *Proceedings of the National Academy of Sciences* 99.suppl 3 (2002), pp. 7280–7287. ISSN: 0027-8424.

[7] GE Bradley. “A proposed mathematical model for computer prediction of crowd movements and their associated risks”. In: *Engineering for crowd safety. Amsterdam: Elsevier* (1993), pp. 303–11.

[8] Michael Bratman. “Intention, plans, and practical reason”. In: (1987).

[9] Simone Brienza et al. “A low-cost sensing system for cooperative air quality monitoring in urban areas”. In: *Sensors* 15.8 (2015), pp. 12242–12259. ISSN: 1424-8220.

[10] R Challenger, CW Clegg, and MA Robinson. “Understanding crowd behaviours: Supporting evidence”. In: *Understanding Crowd Behaviours (Crown, 2009)* (2009), pp. 1–326.

[11] S.B. Chaudhury, M. Sengupta, and K. Mukherjee. "Vibration Monitoring of Rotating Machines Using MEMS Accelerometer". In: *International Journal of Scientific Engineering and Research* 2.9 (2014). ISSN: 2347-3878.

[12] Xuwei Chen and Franklin B Zhan. "Agent-based modelling and simulation of urban evacuation: relative effectiveness of simultaneous and staged evacuation strategies". In: *Journal of the Operational Research Society* 59.1 (2008), pp. 25–33. ISSN: 0160-5682.

[13] G. Ciuti et al. "MEMS Sensor Technologies for Human Centred Applications in Healthcare Physical Activities, Safety and Environmental Sensing: A Review on Research Activities in Italy." In: *Sensors* 15.3 (2015), pp. 6441–6468. ISSN: 1424-8220.

[14] Rinaldo M Colombo and Massimiliano D Rosini. "Pedestrian flows and non classical shocks". In: *Mathematical Methods in the Applied Sciences* 28.13 (2005), pp. 1553–1567. ISSN: 1099-1476.

[15] D. Dai and Y. Zhang. "An agent based model to simulate evacuation in a stadium". In: *Conference on Agent Based Modeling in Transportation Planning and Operations*. 2013.

[16] Mark M Derriso et al. "Industrial Age non-destructive evaluation to Information Age structural health monitoring". In: *Structural Health Monitoring* 13.6 (2014), pp. 591–600. DOI: 10.1177/1475921714546061. eprint: https://doi.org/10.1177/1475921714546061. URL: https://doi.org/10.1177/1475921714546061.

[17] Scott W. Doebling, Charles R. Farrar, and Michael B. Prime. "A Summary Review of Vibration-Based Damage Identification Methods". In: *Identification Methods," The Shock and Vibration Digest* 30 (1998), pp. 91–105.

[18] Scott W. Doebling, Charles R. Farrar, and Michael B. Prime. "Power mode shapes for early damage detection in linear structures". In: *Journal of Sound and Vibration* 324.1-2 (2009), pp. 40–56.

[19] Yilmaz E. et al. "The virtual marathon: Parallel computing supports crowd simulations". In: *IEEE computer graphics and applications* 4 (2009), pp. 26–33. ISSN: 0272-1716.

[20] FEMA. *P58-1, Seismic Performance Assessment of Buildings, Vol.1: Methodology*. Government Document. 2012.

[21] FEMA. *P58-2, Seismic Performance Assessment of Buildings: Implementation Guide*. Government Document. 2012.

[22] Robert J Fisher. "Social desirability bias and the validity of indirect questioning". In: *Journal of consumer research* (1993), pp. 303–315. ISSN: 0093-5301.

[23] M. Georgeff and A. Rao. "Rational software agents: from theory to practice". In: *Agent technology*. Springer, 1998, pp. 139–160.

[24] Chopra A.K. Goel R.K. "Period Formulas for Moment-Resisting Frame Buildings". In: *Journal of Structural Engineering* 123.11 (1997), pp. 1454–1461. ISSN: 0733–9445.

[25] Steve Gwynne et al. "A review of the methodologies used in the computer simulation of evacuation from the built environment". In: *Building and Environment* 34.6 (1999), pp. 741–749. ISSN: 0360-1323.

[26] Chen W. H. et al. "Damage identification based on power spectral density sensitivity analysis of structural responses," in: vol. 919-921. 2014, pp. 45–50.

[27] Dirk Helbing, Illés Farkas, and Tamas Vicsek. "Simulating dynamical features of escape panic". In: *Nature* 407.6803 (2000), pp. 487–490. ISSN: 0028-0836.

[28] Mingyuan Hu et al. "A Multi-Stage Method for Connecting Participatory Sensing and Noise Simulations". In: *Sensors* 15.2 (2015), pp. 2265–2282. ISSN: 1424-8220.

[29] Helmut Jungermann. "A psychological model of emergency evacuation from double-deck aircraft". In: *5th Australian Aviaton Psychology Symposium, Manly/Sydney*. Vol. 176. 2000.

[30] Ronald Kok, Cosme Furlong, and Ryszard J. Pryputniewicz. "Development of a Wireless MEMS Inertial System for Health Monitoring of Structures". In: *MRS Proceedings* 785 (2003), p. D11.5. DOI: 10.1557/PROC-785-D11.5.

[31] Qingkai Kong et al. "MyShake: A smartphone seismic network for earthquake early warning and beyond". In: *Science Advances* 2.2 (2016). DOI: 10.1126/sciadv.1501055. eprint: http://advances.sciencemag.org/content/2/2/e1501055.full.pdf. URL: http://advances.sciencemag.org/content/2/2/e1501055.

[32] Chin Yang Lee. "An algorithm for path connections and its applications". In: *Electronic Computers, IRE Transactions on* 3 (1961), pp. 346–365.

[33] Seung Ho Lee. "Integrated human decision behavior modeling under an extended belief-desire-intention framework". In: *Proceedings of the 2008 Winter Simulation Conference*. S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, J. W. Fowler Editors, 2009.

[34] Seungho Lee and Young-Jun Son. "Integrated human decision making model under belief-desire-intention framework for crowd simulation". In: *Simulation Conference, 2008. WSC 2008. Winter*. IEEE, 2008, pp. 886–894. ISBN: 142442707X.

[35] Yoon Soo Lee and Ali Malkawi. "Simulating human behavior: an agent-based modeling approach". In: *Proceedings of the 13th IBPSA Conference, Chambéry*. 2013.

[36] Paulo Leitao, Udo Inden, and Claus-Peter Rückemann. "Parallelising multi-agent systems for high performance computing". In: (2013). ISSN: 1612083102.

[37] Fang Li et al. "Pedestrian evacuation modeling and simulation on metro platforms considering panic impacts". In: *Procedia-Social and Behavioral Sciences* 138 (2014), pp. 314–322. ISSN: 1877-0428.

[38] Michael K Lindell et al. *Fundamentals of emergency management*. FEMA Washington, DC, 2006.

[39] Silvia Mazzoni et al. "OpenSees command language manual". In: *Pacific Earthquake Engineering Research (PEER) Center* (2006).

[40] Ekin Ozer, Maria Q. Feng, and Dongming Feng. "Citizen Sensors for SHM: Towards a Crowdsourcing Platform". In: *Sensors* 15.6 (2015), pp. 14591–14614. ISSN: 1424-8220.

[41] Cimellaro G P et al. "Rapid building damage assessment system using mobile phone technology". In: *Earthquake Engineering and Engineering Vibration* 13.3 (2014), pp. 519–520. ISSN: 1671-3664.

[42] Welch P. "The use of fast Fourier transform for the estimation of power spectra: a method based on time averaging over short, modified periodograms". In: *IEEE Transactions on Audio and Electroacoustics* 15.2 (1967), pp. 70–73. ISSN: 0018-9278. DOI: 10.1109/TAU.1967.1161901.

[43] Adam Perkins, Brendan Ryan, and Peer-Olaf Siebers. "Modelling and Simulation of Rail Passengers to Evaluate Methods to Reduce Dwell Times". In: *Proceedings of the 14th International Conference on Modeling and Applied Simulation (MAS2015)*. 2015.

[44] Michael J Quinn, Ronald A Metoyer, and Katharine Hunter-Zaworski. "Parallel implementation of the social forces model". In: *Proceedings of the Second International Conference in Pedestrian and Evacuation Dynamics*. Citeseer, 2010, pp. 63–74.

[45] Bryan Raney et al. "An agent-based microsimulation model of Swiss travel: First results". In: *Networks and Spatial Economics* 3.1 (2003), pp. 23–41. ISSN: 1566-113X.

[46] Dashti S. et al. "The Reliability of Phones as Seismic Sensors". In: *In Proceedings of the World Conference Earthquake Engineering* (Sept. 2012).

[47] Thomas C Schelling. "Dynamic models of segregation†". In: *Journal of mathematical sociology* 1.2 (1971), pp. 143–186. ISSN: 0022-250X.

[48] Thomas C Schelling. "Models of segregation". In: *The American Economic Review* (1969), pp. 488–493. ISSN: 0002-8282.

[49] M. Shanthi and E. G. Ryajan. "Agent Based Cellular Automata: A Novel Approach for Modeling Spatiotemporal Growth Processes". In: *International Journal of Application or Innovation in Engineering and Management (IJAIEM)* 1.3 (2012). ISSN: 2319-4847.

[50] Joseph L Smith and James T Brokaw. "Agent based simulation of human movements during emergency evacuations of facilities". In: *Structures Congress*. 2008, pp. 1–10.

[51] Michael Kinsey Steve Gwynne Erica D. Kuligowski. "Human behavior in fire - Model development and application". In: *6th International Symposium on Human Behaviour in Fire*. 2015.

[52] Christian Stolz and Manfred Neumair. "Structural Health Monitoring, In-service Experience, Benefit and Way Ahead". In: *Structural Health Monitoring* 9.3 (2010), pp. 209–217. DOI: 10.1177/1475921710366655. eprint: https://doi.org/10.1177/1475921710366655. URL: https://doi.org/10.1177/1475921710366655.

[53] Ron Sun. *Cognition and multi-agent interaction: From cognitive modeling to social simulation*. Cambridge University Press, 2006. ISBN: 0521839645.

[54] T Takahashi et al. "Shaking Table Test for Indoor Human Response and Evacuation Limit, journal of 5th International Conference on Earthquake Engineering". In: (2010).

[55] Fangqin Tang and Aizhu Ren. "Agent-based evacuation model incorporating fire scene and building geometry". In: *Tsinghua Science and Technology* 13.5 (2008), pp. 708–714. ISSN: 1007-0214.

[56] Jan C. Thiele. "Package RNetLogo". In: (2013).

[57] T. Torfs et al. "Low Power Wireless Sensor Network for Building Monitoring". In: *IEEE Sensors Journal* 13.3 (Mar. 2013), pp. 909–915. ISSN: 1530-437X. DOI: 10.1109/JSEN.2012.2218680.

[58] Jason Tsai et al. "Agent-based evacuation modeling: Simulating the Los Angeles international airport". In: *Proceedings of the workshop on emergency management: Incident, resource, and supply chain management*. 2009.

[59] Jason Tsai et al. "ESCAPES: evacuation simulation with children, authorities, parents, emotions, and social comparison". In: *Proceedings of The 10th International Conference on Autonomous Agents and Multiagent Systems-Volume 2*. International Foundation for Autonomous Agents and Multiagent Systems, 2009, pp. 457–464. ISBN: 0982657161.

[60] Benevicius V., Ostasevicius V., and Gaidys R. “Identification of Capacitive MEMS Accelerometer Structure Parameters for Human Body Dynamics Measurements”. In: *Sensors* 13.9 (2013), pp. 11184–11195. ISSN: 1424-8220.

[61] J. Von Neumann. “John von Neumann’s Cellular Automata”. In: (2010). ISSN: 1940-5030. URL: http://embryo.asu.edu/handle/10776/2009.

[62] B.J. Vreugdenhil, N. Bellomo, and P. S. Townsend. “Using Crowd Modelling in Evacuation Decision Making”. In: *Proceedings of The ISCRAM 2015 Conference*. 2015.

[63] Hui Xi, Seungho Lee, and Young-Jun Son. “An integrated pedestrian behavior model based on extended decision field theory and social force model”. In: *Human-in-the-Loop Simulations*. Springer, 2011, pp. 69–95. ISBN: 0857298828.

[64] Weihao Yin et al. “An agent-based modeling system for travel demand simulation for hurricane evacuation”. In: *Transportation research part C: emerging technologies* 42 (2014), pp. 44–59. ISSN: 0968-090X.

[65] Xiaoping Zheng, Tingkuan Zhong, and Mengting Liu. “Modeling crowd evacuation of a building based on seven methodological approaches”. In: *Building and Environment* 44.3 (2009), pp. 437–445. ISSN: 0360-1323.

[66] Kashif Zia et al. “An agent-based parallel geo-simulation of urban mobility during city-scale evacuation”. In: *Simulation* (2013), pp. 1244–1267. ISSN: 0037-5497.

[67] Kashif Zia et al. “Structural damage identification based on power spectral density sensitivity analysis of dynamic responses”. In: *Computers Structures* 146 (2014), pp. 176–184.

Appendix A

Survey: English Version

Resilience Survey (ENG)

You have been invited to take part in a research study. The information in this form is provided to help you if you want to take part in this survey.

What is the purpose of this research study?
The goal of this project is to use an emergency scenario survey to analyze how people evaluate emergencies situations, to develop an accurate simulation model of an emergency evacuation, taking into account human behavior, damage scenarios and parallel computing devices.

Will the information that is obtained from me be kept confidential?
The personal information that you will be asked to give are age, sex and highest school degree, so your identity will not be known by the Principal Investigator. The people who will have access to that information will be the research team members, specifically the Principal Investigator and the Advisors. Your responses will be confidential. You and your responses will not be identified in any reports or publications resulting from the study.

May I change my mind about participating?
Your participation in this study is voluntary. You may decide to not begin or to stop the study at any time.

Advice for the goal achievement
In order to achieve the goal of this survey, your answers and concentration are FUNDAMENTAL. Please answer all the questions concentrating on the situation that is described at the beginning of each section. Please follow each request you find during the questionnaire and answer them with honesty (remember that nobody will know your identity). Please, do not compete the survey more than one time.

Please, watch this short video before filling the survey.

Please read all the information in the following pages and read each question with attention. Please answer each question with the maximum honesty.

Each section regards the evacuation of a building: you are in panic, you have to evacuate, but in the last cases you have also your family/friends with you. In each section image, you are the person (injured or not) in the FOREGROUND.

What is your sex? *

How old are you? *

What is your job? *

Case 1 (Questions 1-3)

During the evacuation, you are alone: so you do not know anyone. Fortunately, you are not injured, so you can walk and run and you are able to see and hear well the most important things of the environment, even if there is crowd and smoke. Fortunately you see the emergency exit!

1 - You see a group of people running in a different direction respect the emergency exit one. How likely will you follow them? *

- I will follow them: maybe they know a better exit!
- Maybe I will follow them: maybe they know a better exit!
- I don't know.
- Maybe I will not follow them: I will exit on my own through the emergency exit!
- I will not follow them: I will exit on my own through the emergency exit!

2 - You find a not seriously injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe it's not necessary to help him: paramedics will arrive soon!
- It's not necessary to help him: paramedics will arrive soon!

3 - You find a SERIOUSLY injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe my help is not useful for him: paramedics are arriving soon!
- My help is not useful for him: paramedics are arriving soon!

Case 2 (Questions 4-6)

During the evacuation, you are alone: so you do not know anyone.
Fortunately, you are not injured, so you can walk and run and you are able to see and hear well the most important things of the environment, even if there is crowd and smoke.
DAMN, you don't find the emergency exit!

4 - You see a group of people running in a certain direction. How likely will you follow them? *

- I will follow them.
- Maybe I will follow them.
- I don't know.
- Maybe I will not follow them.
- I will not follow them.

5 - You find a not seriously injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe it's not necessary to help him: paramedics will arrive soon!
- It's not necessary to help him: paramedics will arrive soon!

6 - You find a SERIOUSLY injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe my help is not useful for him: paramedics are arriving soon!
- My help is not useful for him: paramedics are arriving soon!

Case 3 (Questions 7-9)

During the evacuation, you are alone: so you do not know anyone. YOU ARE INJURED, so you can not run, you have pain if you try to walk, but you are able to see and hear with a bit of difficulty most of the important things of the environment, even if there is crowd and smoke. Fortunately you see the emergency exit!

7 - You see a group of people running in a different direction respect the emergency exit one. How likely will you follow them? *

- I will follow them: maybe they know a better exit!
- Maybe I will follow them: maybe they know a better exit!
- I don't know.
- Maybe I will not follow them: I will exit on my own through the emergency exit!
- I will not follow them: I will exit on my own through the emergency exit!

8 - You find a not seriously injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe it's not necessary to help him: paramedics will arrive soon!
- It's not necessary to help him: paramedics will arrive soon!

9 - You find a SERIOUSLY injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe my help is not useful for him: paramedics are arriving soon!
- My help is not useful for him: paramedics are arriving soon!

Case 4 (Questions 10-12)

During the evacuation, you are alone: so you do not know anyone. YOU ARE INJURED, so you can not run, you have pain if you try to walk, but you are able to see and hear with a bit of difficulty most of the important things of the environment, even if there is crowd and smoke. DAMN, you can not see the emergency exit!

10 - You see a group of people running in certain direction. How likely will you follow them? *

- I will follow them.
- Maybe I will follow them.
- I don't know.
- Maybe I will not follow them.
- I will not follow them.

11 - You find a not seriously injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe it's not necessary to help him: paramedics will arrive soon!
- It's not necessary to help him: paramedics will arrive soon!

12 - You find a SERIOUSLY injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe my help is not useful for him: paramedics are arriving soon!
- My help is not useful for him: paramedics are arriving soon!

Case 5 (Questions 13-16)

During the evacuation, you are with YOUR FAMILY or with your friends. You are not injured, so you can run accordingly to the capacities of all your group, and you are able to see and hear most of the important things of the environment, even if there is crowd and smoke. Fortunately you can see the emergency exit!

13 - You are EVACUATING the building, but... DAMN! You can not find a member of your family/friends!!! What will you do? *

- I will come back and look for the missing person.
- Maybe I will come back and look for the missing person.
- I don't know.
- Maybe I will continue the evacuation: paramedics are more experienced than me, they will give him a better help.
- I will continue the evacuation: paramedics are more experienced than me, they will give him a better help.

14 - You see a group of people running in a different direction respect the emergency exit one. How likely will you follow them? *

- I will follow them: maybe they know a better exit!
- Maybe I will follow them: maybe they know a better exit!
- I don't know.
- Maybe I will not follow them: I will exit on my own through the emergency exit!
- I will not follow them: I will exit on my own through the emergency exit!

15 - You find a not seriously injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe it's not necessary to help him: paramedics will arrive soon!
- It's not necessary to help him: paramedics will arrive soon!

16 - You find a SERIOUSLY injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe my help is not useful for him: paramedics are arriving soon!
- My help is not useful for him: paramedics are arriving soon!

Case 6 (Questions 17-20)

During the evacuation, you are with YOUR FAMILY or with your friends. You are not injured, so you can run accordingly to the capacities of all your group, and you are able to see and hear most of the important things of the environment, even if there is crowd and smoke. DAMN! You do not find the emergency exit!

17 - You are EVACUATING the building, but... DAMN! You can not find a member of your family/friends!!! What will you do? *

- I will come back and look for the missing person.
- Maybe I will come back and look for the missing person.
- I don't know.
- Maybe I will continue the evacuation: paramedics are more experienced than me, they will give him a better help.
- I will continue the evacuation: paramedics are more experienced than me, they will give him a better help.

18 - You see a group of people running in a certain direction. How likely will you follow them? *

- ○ I will follow them.
- ○ Maybe I will follow them.
- ○ I don't know.
- ○ Maybe I will not follow them.
- ○ I will not follow them.

19 - You find a not seriously injured person. How likely will you give him a help (or first aid)? *

- ○ I will help him.
- ○ Maybe I will help him.
- ○ I don't know.
- ○ Maybe it's not necessary to help him: paramedics will arrive soon!
- ○ It's not necessary to help him: paramedics will arrive soon!

20 - You find a SERIOUSLY injured person. How likely will you give him a help (or first aid)? *

- ○ I will help him.
- ○ Maybe I will help him.
- ○ I don't know.
- ○ Maybe my help is not useful for him: paramedics are arriving soon!
- ○ My help is not useful for him: paramedics are arriving soon!

Case 7 (Questions 21-24)

During the evacuation, you are with YOUR FAMILY or with your friends. YOU ARE INJURED, so you can not run, you have pain if you try to walk, but you are able to see and hear with a bit of difficulty most of the important things of the environment, even if there is crowd and smoke. Fortunately you can see the emergency exit!

21 - You are EVACUATING the building, but... DAMN! You can not find a member of your family/friends!!! What will you do? *

- I will come back and look for the missing person.
- Maybe I will come back and look for the missing person.
- I don't know.
- Maybe I will continue the evacuation: paramedics are more experienced than me, they will give him a better help.
- I will continue the evacuation: paramedics are more experienced than me, they will give him a better help.

22 - You see a group of people running in a different direction respect the emergency exit one. How likely will you follow them? *

- I will follow them: maybe they know a better exit!
- Maybe I will follow them: maybe they know a better exit!
- I don't know.
- Maybe I will not follow them: I will exit on my own through the emergency exit!
- I will not follow them: I will exit on my own through the emergency exit!

23 - You find a not seriously injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe it's not necessary to help him: paramedics will arrive soon!
- It's not necessary to help him: paramedics will arrive soon!

24 - You find a SERIOUSLY injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe my help is not useful for him: paramedics are arriving soon!
- My help is not useful for him: paramedics are arriving soon!

Case 8 (Questions 25-28)

During the evacuation, you are with YOUR FAMILY or with your friends. YOU ARE INJURED, so you can not run, you have pain if you try to walk, but you are able to see and hear with a bit of difficulty most of the important things of the environment, even if there is crowd and smoke. DAMN! You can not find the emergency exit!

25 - You are EVACUATING the building, but... DAMN! You can not find a member of your family/friends!!! What will you do? *

- I will come back and look for the missing person.
- Maybe I will come back and look for the missing person.
- I don't know.
- Maybe I will continue the evacuation: paramedics are more experienced than me, they will give him a better help.
- I will continue the evacuation: paramedics are more experienced than me, they will give him a better help.

26 - You see a group of people running in a certain direction. How likely will you follow them? *

- I will follow them.
- Maybe I will follow them.
- I don't know.
- Maybe I will not follow them.
- I will not follow them.

27 - You find a not seriously injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe it's not necessary to help him: paramedics will arrive soon!
- It's not necessary to help him: paramedics will arrive soon!

28 - You find a SERIOUSLY injured person. How likely will you give him a help (or first aid)? *

- I will help him.
- Maybe I will help him.
- I don't know.
- Maybe my help is not useful for him: paramedics are arriving soon!
- My help is not useful for him: paramedics are arriving soon!

« Indietro **Invia**

100%: completato.

Non inviare mai le password tramite Moduli Google.

Appendix B

Survey: Italian Version

Resilience survey (IT)

Sei stato/a invitato/a a prender parte ad uno studio per il Pacific Earthquake Engineering Research Center (PEER), ente di ricerca presso l'Università della California, Berkeley. Per favore, leggi questa descrizione che ti aiuterà a capire e scegliere se proseguire con il completamento del questionario.

Quali sono gli obiettivi di questo progetto di ricerca?
Gli obiettivi sono quelli di realizzare un modello di comportamento umano per simulare l'evacuazione di edifici ed infrastrutture durante una situazione di emergenza. Verranno impiegati anche numerosi scenari di danno e diversi fattori scatenanti situazioni di emergenza. I calcoli saranno effettuati mediante parallel computing.

Le informazioni che fornisco sono confidenziali?
Certamente, ti chiediamo solamente di fornirci i tuoi dati relativi a sesso, età e percorso di studi, dunque la tua identità non sarà mai rivelata, nemmeno a chi gestisce questo questionario. Le informazioni relative alla tua posizione NON saranno raccolte dal questionario. Inoltre, la tua risposta non sarà mai analizzata singolarmente e non sarà mai pubblicata su articoli specialistici o simili.

Posso cambiare idea ed abbandonare il questionario?
Certamente, puoi cambiare idea in qualsiasi momento, fino a quando non darai conferma di invio delle informazioni: sarà sufficiente chiudere la finestra sul tuo browser e confermare l'uscita dal questionario aperto.

Alcune informazioni prima di procedere al questionario.
Per raggiungere la precisione voluta dal team di ricerca, le tue risposte ed il tuo impegno sono FONDAMENTALI. Ti chiediamo di leggere attentamente ogni frase ed ogni domanda, prestando attenzione ad ogni video o disegno che ti viene mostrato e rispondendo con il massimo dell'onestà, anche se la riposta che dai può sembrare "moralmente inadeguata" (ricorda che la tua identità non la saprà nessuno).
Ti chiediamo infine di completare il questionario una sola volta.

Per favore, guarda questo video prima di procedere con il questionario.

« Indietro   Continua »

18% completato

Per favore, leggi con attenzione ogni informazione presentata nelle pagine seguenti e rispondi ad ogni domanda con la massima attenzione.

Ogni sezione riguarda l'evacuazione di un edificio: sei nel panico, devi uscire ma, negli ultimi casi, hai anche i tuoi parenti/amici. In ogni immagine delle prossime pagine, tu rappresenti la persona (ferita o no) in primo piano.

Qual è il tuo sesso? *

Quanti anni hai? *

Che lavoro fai? *

« Indietro   Continua »

27% completato

Scenario 1

Mentre sei nell'edificio, sei da solo e non conosci nessuno. Fortunatamente non sei ferito, quindi puoi correre senza problemi e vedere o sentire la maggior parte delle informazioni presenti durante l'evacuazione, anche se c'è molto fumo. Fortunatamente, vedi l'uscita di emergenza!

1 - Ad un certo punto, vedi un gruppo di persone che sta correndo verso un'uscita diversa da quella di emergenza. Cosa fai? *

- Li seguo, magari conoscono una via migliore.
- Probabilmente li seguo, magari conoscono una via migliore.
- Non lo so.
- Probabilmente non li seguo: vado verso l'uscita di emergenza!
- Non li seguo: vado verso l'uscita di emergenza!

2 - Vedi una persona leggermente ferita: cosa fai? *

- Le presto soccorso.
- Forse le presto soccorso.
- Non lo so.
- Forse non è necessario soccorrerla: tra poco arriveranno i soccorsi!
- Non è necessario soccorrerla: tra poco arriveranno i soccorsi!

3 - Vedi una persona gravemente ferita: cosa fai? *

- Le presto soccorso.
- Forse le presto soccorso.
- Non lo so.
- Forse non è conveniente soccorrerla: tra poco arriveranno i soccorsi!
- Non sono in grado di soccorrerla: tra poco arriveranno i soccorsi!

« Indietro   Continua »

36% completato

Scenario 2 (Domande 4-6)

Mentre sei nell'edificio, sei da solo e non conosci nessuno. Fortunatamente non sei ferito, quindi puoi correre senza problemi e vedere o sentire la maggior parte delle informazioni presenti durante l'evacuazione, anche se c'è molto fumo. DANNAZIONE, non vedi l'uscita di emergenza!

4 - Ad un certo punto, vedi un gruppo di persone che sta correndo in una certa direzione. Cosa fai? *

- ○ Li seguo.
- ○ Probabilmente li seguo.
- ○ Non lo so.
- ○ Probabilmente non li seguo.
- ○ Non li seguo.

5 - Vedi una persona leggermente ferita: cosa fai? *

- ○ Le presto soccorso.
- ○ Forse le presto soccorso.
- ○ Non lo so.
- ○ Forse non è necessario soccorrerla: tra poco arriveranno i soccorsi!
- ○ Non è necessario soccorrerla: tra poco arriveranno i soccorsi!

6 - Vedi una persona gravemente ferita: cosa fai? *

- ○ Le presto soccorso.
- ○ Forse le presto soccorso.
- ○ Non lo so.
- ○ Forse non è conveniente soccorrerla: tra poco arriveranno i soccorsi!
- ○ Non sono in grado di soccorrerla: tra poco arriveranno i soccorsi!

« Indietro | Continua »

45% completato

Scenario 3 (Domande 7-9)

Mentre sei nell'edificio, sei da solo e non conosci nessuno. SEI FERITO! Non riesci a correre, stenti a camminare ed a e vedere o sentire le informazioni presenti durante l'evacuazione. C'è molto fumo. Fortunatamente, vedi l'uscita di emergenza!

7 - Ad un certo punto, vedi un gruppo di persone che sta correndo verso un'uscita diversa da quella di emergenza. Cosa fai? *

- ○ Li seguo, magari conoscono una via migliore.
- ○ Probabilmente li seguo, magari conoscono una via migliore.
- ○ Non lo so.
- ○ Probabilmente non li seguo: vado verso l'uscita di emergenza!
- ○ Non li seguo: vado verso l'uscita di emergenza!

8 - Vedi una persona leggermente ferita: cosa fai? *

- ○ Le presto soccorso.
- ○ Forse le presto soccorso.
- ○ Non lo so.
- ○ Forse non è necessario soccorrerla: tra poco arriveranno i soccorsi!
- ○ Non è necessario soccorrerla: tra poco arriveranno i soccorsi!

9 - Vedi una persona gravemente ferita: cosa fai? *

- ○ Le presto soccorso.
- ○ Forse le presto soccorso.
- ○ Non lo so.
- ○ Forse non è conveniente soccorrerla: tra poco arriveranno i soccorsi!
- ○ Non sono in grado di soccorrerla: tra poco arriveranno i soccorsi!

« Indietro **Continua »**

54% completato

Scenario 4 (Domande 10-12)

Mentre sei nell'edificio, sei da solo e non conosci nessuno. SEI FERITO! Non riesci a correre, stenti a camminare ed a e vedere o sentire le informazioni presenti durante l'evacuazione. C'è molto fumo. DANNAZIONE, non vedi l'uscita di emergenza!

10 - Ad un certo punto, vedi un gruppo di persone che sta correndo in una certa direzione. Cosa fai? *

- ○ Li seguo.
- ○ Probabilmente li seguo.
- ○ Non lo so.
- ○ Probabilmente non li seguo.
- ○ Non li seguo.

11 - Vedi una persona leggermente ferita: cosa fai? *

- ○ Le presto soccorso.
- ○ Forse le presto soccorso.
- ○ Non lo so.
- ○ Forse non è necessario soccorrerla: tra poco arriveranno i soccorsi!
- ○ Non è necessario soccorrerla: tra poco arriveranno i soccorsi!

12 - Vedi una persona gravemente ferita: cosa fai? *

- ○ Le presto soccorso.
- ○ Forse le presto soccorso.
- ○ Non lo so.
- ○ Forse non è conveniente soccorrerla: tra poco arriveranno i soccorsi!
- ○ Non sono in grado di soccorrerla: tra poco arriveranno i soccorsi!

« Indietro | Continua »

63% completato

Scenario 5 (Domande 13-16)

Mentre sei nell'edificio, sei insieme alla tua FAMIGLIA o ad un gruppo di amici. Fortunatamente non sei ferito, quindi puoi correre senza problemi e vedere o sentire la maggior parte delle informazioni presenti durante l'evacuazione, anche se c'è molto fumo. Fortunatamente, vedi l'uscita di emergenza!

13 - Dannazione! Non trovi un membro della famiglia/amico! Cosa fai? *

- Lo cerco.
- Probabilmente lo cerco.
- Non lo so.
- Probabilmente non lo cerco: i soccorritori sono esperti e gli daranno un aiuto migliore!
- Non lo cerco: i soccorritori sono esperti e gli daranno un aiuto migliore!

14 - Ad un certo punto, vedi un gruppo di persone che sta correndo verso un'uscita diversa da quella di emergenza. Cosa fai? *

- Li seguo, magari conoscono una via migliore.
- Probabilmente li seguo, magari conoscono una via migliore.
- Non lo so.
- Probabilmente non li seguo: vado verso l'uscita di emergenza!
- Non li seguo: vado verso l'uscita di emergenza!

15 - Vedi una persona leggermente ferita: cosa fai? *

- Le presto soccorso.
- Forse le presto soccorso.
- Non lo so.
- Forse non è necessario soccorrerla: tra poco arriveranno i soccorsi!
- Non è necessario soccorrerla: tra poco arriveranno i soccorsi!

16 - Vedi una persona gravemente ferita: cosa fai? *

- Le presto soccorso.
- Forse le presto soccorso.
- Non lo so.
- Forse non è conveniente soccorrerla: tra poco arriveranno i soccorsi!
- Non sono in grado di soccorrerla: tra poco arriveranno i soccorsi!

« Indietro   Continua »

72% completato

Scenario 6 (Domande 17-20)

Mentre sei nell'edificio, sei insieme alla tua FAMIGLIA o ad un gruppo di amici. Fortunatamente non sei ferito, quindi puoi correre senza problemi e vedere o sentire la maggior parte delle informazioni presenti durante l'evacuazione, anche se c'è molto fumo. DANNAZIONE, non trovi l'uscita di emergenza!

17 - Dannazione! Non trovi un membro della famiglia/amico! Cosa fai? *

- Lo cerco.
- Probabilmente lo cerco.
- Non lo so.
- Probabilmente non lo cerco: i soccorritori sono esperti e gli daranno un aiuto migliore!
- Non lo cerco: i soccorritori sono esperti e gli daranno un aiuto migliore!

18 - Ad un certo punto, vedi un gruppo di persone che sta correndo in una certa direzione. Cosa fai? *

- Li seguo.
- Probabilmente li seguo.
- Non lo so.
- Probabilmente non li seguo.
- Non li seguo.

19 - Vedi una persona leggermente ferita: cosa fai? *

- Le presto soccorso.
- Forse le presto soccorso.
- Non lo so.
- Forse non è necessario soccorrerla: tra poco arriveranno i soccorsi!
- Non è necessario soccorrerla: tra poco arriveranno i soccorsi!

20 - Vedi una persona gravemente ferita: cosa fai? *

- Le presto soccorso.
- Forse le presto soccorso.
- Non lo so.
- Forse non è conveniente soccorrerla: tra poco arriveranno i soccorsi!
- Non sono in grado di soccorrerla: tra poco arriveranno i soccorsi!

« Indietro | Continua »

81% completato

Scenario 7 (Domande 21-24)

Mentre sei nell'edificio, sei insieme alla tua FAMIGLIA o ad un gruppo di amici. SEI FERITO! Non riesci a correre, stenti a camminare ed a e vedere o sentire le informazioni presenti durante l'evacuazione. C'è molto fumo. Fortunatamente, vedi l'uscita di emergenza!

21 - Dannazione! Non trovi un membro della famiglia/amico! Cosa fai? *

- Lo cerco.
- Probabilmente lo cerco.
- Non lo so.
- Probabilmente non lo cerco: i soccorritori sono esperti e gli daranno un aiuto migliore!
- Non lo cerco: i soccorritori sono esperti e gli daranno un aiuto migliore!

22 - Ad un certo punto, vedi un gruppo di persone che sta correndo verso un'uscita diversa da quella di emergenza. Cosa fai? *

- ○ Li seguo, magari conoscono una via migliore.
- ○ Probabilmente li seguo, magari conoscono una via migliore.
- ○ Non lo so.
- ○ Probabilmente non li seguo: vado verso l'uscita di emergenza!
- ○ Non li seguo: vado verso l'uscita di emergenza!

23 - Vedi una persona leggermente ferita: cosa fai? *

- ○ Le presto soccorso.
- ○ Forse le presto soccorso.
- ○ Non lo so.
- ○ Forse non è necessario soccorrerla: tra poco arriveranno i soccorsi!
- ○ Non è necessario soccorrerla: tra poco arriveranno i soccorsi!

24 - Vedi una persona gravemente ferita: cosa fai? *

- ○ Le presto soccorso.
- ○ Forse le presto soccorso.
- ○ Non lo so.
- ○ Forse non è conveniente soccorrerla: tra poco arriveranno i soccorsi!
- ○ Non sono in grado di soccorrerla: tra poco arriveranno i soccorsi!

« Indietro | Continua »

90% completato

Scenario 8 (Domande 25-28)

Mentre sei nell'edificio, sei insieme alla tua FAMIGLIA o ad un gruppo di amici. SEI FERITO! Non riesci a correre, stenti a camminare ed a e vedere o sentire le informazioni presenti durante l'evacuazione. C'è molto fumo. DANNAZIONE, non riesci a trovare l'uscita di emergenza!

25 - Dannazione! Non trovi un membro della famiglia/amico! Cosa fai? *

- Lo cerco.
- Probabilmente lo cerco.
- Non lo so.
- Probabilmente non lo cerco: i soccorritori sono esperti e gli daranno un aiuto migliore.
- Non lo cerco: i soccorritori sono esperti e gli daranno un aiuto migliore.

26 - Ad un certo punto, vedi un gruppo di persone che sta correndo in una certa direzione. Cosa fai? *

- Li seguo.
- Probabilmente li seguo.
- Non lo so.
- Probabilmente non li seguo.
- Non li seguo.

27 - Vedi una persona leggermente ferita: cosa fai? *

- Le presto soccorso.
- Forse le presto soccorso.
- Non lo so.
- Forse non è necessario soccorrerla: tra poco arriveranno i soccorsi!
- Non è necessario soccorrerla: tra poco arriveranno i soccorsi!

28 - Vedi una persona gravemente ferita: cosa fai? *

- Le presto soccorso.
- Forse le presto soccorso.
- Non lo so.
- Forse non è conveniente soccorrerla: tra poco arriveranno i soccorsi!
- Non sono in grado di soccorrerla: tra poco arriveranno i soccorsi!

« Indietro | Invia

100%: completato.

Non inviare mai le password tramite Moduli Google.

Appendix C

Survey Results

CASE 1
ALONE
NOT INJURED
SEE EMERGENCY EXIT

QUESTION 1		
You see a group running in another direction		
ANSWER	COUNT	PROB
Follow	6	0.042
Maybe	16	0.112
Don'k know	6	0.042
Maybe no	59	0.413
Don't follow	56	0.392
TOT	143	1

QUESTION 2		
You see a not seriously injured person.		
ANSWER	COUNT	PROB
Help	84	0.587
Maybe	40	0.280
Don'k know	5	0.035
Maybe no	9	0.063
Don't help	5	0.035
TOT	143	1

QUESTION 3		
You see a seriously injured person		
ANSWER	COUNT	PROB
Help	78	0.545
Maybe	24	0.168
Don'k know	10	0.070
Maybe no	5	0.035
Don't help	26	0.182
TOT	143	1

Positive + Maybe	0.154
Positive+Maybe+I don't know	0.196

Positive	0.587
Positive + Maybe	0.867

Positive	0.545
Positive + Maybe	0.713

W vector evaluation

	Intervals			Qn.
W=	0.154	0.196	Do you follow the group of people?	1
	0.587	0.867	Do you help a not seriously injured person?	2
	0.545	0.713	Do you help a seriously injured person?	3

	0.144
S*Wavg	0.647
	0.557

	0.031
Wavg-S*Wavg	0.081
	0.072

			Qn.	T matrix		
Wavg=	0.175	Do you follow the group of people?	1	0.255	-0.010	-0.010
	0.727	Do you help a not seriously injured person?	2	-0.010	0.122	-0.010
	0.629	Do you help a seriously injured person?	3	-0.010	-0.010	0.129

CASE 2
ALONE
NOT INJURED
DON'T SEE EMERGENCY EXIT

QUESTION 4		
You see a group running in another direction		
ANSWER	COUNT	PROB
Follow	58	0.406
Maybe	75	0.524
Don'k know	1	0.007
Maybe no	4	0.028
Don't follow	5	0.035
TOT	143	1

QUESTION 5		
You see a not seriously injured person.		
ANSWER	COUNT	PROB
Help	75	0.524
Maybe	35	0.245
Don'k know	15	0.105
Maybe no	13	0.091
Don't help	5	0.035
TOT	143	1

QUESTION 6		
You see a seriously injured person		
ANSWER	COUNT	PROB
Help	73	0.510
Maybe	24	0.168
Don'k know	12	0.084
Maybe no	7	0.049
Don't help	27	0.189
TOT	143	1

Positive + Maybe	0.930
Positive + Maybe + I don't know	0.937

Positive	0.524
Positive + Maybe	0.769

Positive	0.510
Positive + Maybe	0.678

W vector evaluation

W= (Intervals)

Intervals		Question	Qn.
0.930	0.937	Do you follow the group of people?	4
0.524	0.769	Do you help a not seriously injured person?	5
0.510	0.678	Do you help a seriously injured person?	6

SWavg=

0.828
0.567
0.519

Wavg-Swavg

0.106
0.080
0.075

Wavg=

0.934
0.647
0.594

Question	Qn.	T matrix		
Do you follow the group of people?	4	0.127	-0.010	-0.010
Do you help a not seriously injured person?	5	-0.010	0.147	-0.010
Do you help a seriously injured person?	6	-0.010	-0.010	0.153

CASE 3
ALONE
INJURED
SEE EMERGENCY EXIT

QUESTION 7		
You see a group running in another direction		
ANSWER	COUNT	PROB
Follow	12	0.084
Maybe	16	0.112
Don'k know	6	0.042
Maybe no	47	0.329
Don't follow	62	0.434
TOT	143	1

QUESTION 8		
You see a not seriously injured person.		
ANSWER	COUNT	PROB
Help	40	0.280
Maybe	37	0.259
Don'k know	30	0.210
Maybe no	19	0.133
Don't help	17	0.119
TOT	143	1

QUESTION 9		
You see a seriously injured person		
ANSWER	COUNT	PROB
Help	36	0.252
Maybe	32	0.224
Don'k know	21	0.147
Maybe no	6	0.042
Don't help	48	0.336
TOT	143	1

Positive + Maybe	0.196
Positive + Maybe + I don't know	0.238

Positive	0.280
Positive + Maybe	0.538

Positive	0.252
Positive + Maybe	0.476

W vector evaluation

W= (Intervals)

0.196	0.238
0.280	0.538
0.252	0.476

	Qn.
Do you follow the group of people?	7
Do you help a not seriously injured person?	8
Do you help a seriously injured person?	9

S*Wavg

0.187
0.362
0.321

Wavg-S*Wavg

0.029
0.047
0.043

Wavg=

0.217
0.409
0.364

	Qn.	T matrix		
Do you follow the group of people?	7	0.171	-0.010	-0.010
Do you help a not seriously injured person?	8	-0.010	0.128	-0.010
Do you help a seriously injured person?	9	-0.010	-0.010	0.134

CASE 4
ALONE
INJURED
DON'T SEE EMERGENCY EXIT

QUESTION 10		
You see a group running in another direction		
ANSWER	COUNT	PROB
Follow	74	0.517
Maybe	48	0.336
Don'k know	8	0.056
Maybe no	6	0.042
Don't follow	7	0.049
TOT	143	1

QUESTION 11		
You see a not seriously injured person.		
ANSWER	COUNT	PROB
Help	39	0.273
Maybe	33	0.231
Don'k know	32	0.224
Maybe no	16	0.112
Don't help	23	0.161
TOT	143	1

QUESTION 12		
You see a seriously injured person		
ANSWER	COUNT	PROB
Help	30	0.210
Maybe	22	0.154
Don'k know	28	0.196
Maybe no	9	0.063
Don't help	54	0.378
TOT	143	1

Positive + Maybe	0.853
Positive + Maybe + I don't know	0.909

Positive	0.273
Positive + Maybe	0.503

Positive	0.210
Positive + Maybe	0.364

W vector evaluation

S*Wavg	0.786
	0.338
	0.245

Intervals

				Qn.
W=	0.853	0.909	Do you follow the group of people?	10
	0.273	0.503	Do you help a not seriously injured person?	11
	0.210	0.364	Do you help a seriously injured person?	12

Wavg-S*Wavg	0.095
	0.050
	0.041

			Qn.	T matrix		
Wavg=	0.881	Do you follow the group of people?	10	0.115	-0.010	-0.010
	0.388	Do you help a not seriously injured person?	11	-0.010	0.160	-0.010
	0.287	Do you help a seriously injured person?	12	-0.010	-0.010	0.189

CASE 5
FAMILY
NOT INJURED
SEE EMERGENCY EXIT

QUESTION 13		
Search your relatives?		
ANSWER	COUNT	PROB
Yes	124	0.867
Maybe	14	0.098
Don'k know	0	0.000
Maybe no	4	0.028
No	1	0.007
TOT	143	1

Positive + Maybe	0.965
Positive + Maybe + I don't know	0.965

QUESTION 14		
You see a group running in another direction		
ANSWER	COUNT	PROB
Follow	7	0.049
Maybe	14	0.098
Don'k know	5	0.035
Maybe no	46	0.322
Don't follow	71	0.497
TOT	143	1

Positive + Maybe	0.147
Positive + Maybe + I don't know	0.182

QUESTION 15		
You see a not seriously injured person.		
ANSWER	COUNT	PROB
Help	78	0.545
Maybe	45	0.315
Don'k know	8	0.056
Maybe no	7	0.049
Don't help	5	0.035
TOT	143	1

Positive	0.545
Positive + Maybe	0.860

QUESTION 16		
You see a seriously injured person		
ANSWER	COUNT	PROB
Help	69	0.483
Maybe	30	0.210
Don'k know	10	0.070
Maybe no	7	0.049
Don't help	27	0.189
TOT	143	1

Positive	0.483
Positive + Maybe	0.692

W vector evaluation

W=

Intervals			Qn.
0.965	0.965	Do you look for your missing relative/friend?	13
0.147	0.182	Do you follow the group of people?	14
0.545	0.860	Do you help a not seriously injured person?	15
0.483	0.692	Do you help a seriously injured person?	16

Wavg=

		Qn.
0.965	Do you look for your missing relative/friend?	13
0.164	Do you follow the group of people?	14
0.703	Do you help a not seriously injured person?	15
0.587	Do you help a seriously injured person?	16

S*Wavg
0.854
0.125
0.615
0.510

Wavg-S*Wavg
0.111
0.039
0.087
0.077

T matrix			
0.130	-0.010	-0.010	-0.010
-0.010	0.374	-0.010	-0.010
-0.010	-0.010	0.149	-0.010
-0.010	-0.010	-0.010	0.162

CASE 6
FAMILY
NOT INJURED
DON'T SEE EMERGENCY EXIT

QUESTION 17		
Search your relatives?		
ANSWER	COUNT	PROB
Yes	120	0.839
Maybe	16	0.112
Don'k know	2	0.014
Maybe no	3	0.021
No	2	0.014
TOT	143	1

Positive + Maybe	0.951
Positive + Maybe + I don't know	0.965

QUESTION 18		
You see a group running in another direction		
ANSWER	COUNT	PROB
Follow	36	0.252
Maybe	82	0.573
Don'k know	8	0.056
Maybe no	6	0.042
Don't follow	11	0.077
TOT	143	1

Positive + Maybe	0.825
Positive + Maybe + I don't know	0.881

QUESTION 19		
You see a not seriously injured person.		
ANSWER	COUNT	PROB
Help	69	0.483
Maybe	41	0.287
Don'k know	17	0.119
Maybe no	10	0.070
Don't help	6	0.042
TOT	143	1

Positive	0.483
Positive + Maybe	0.769

QUESTION 20		
You see a seriously injured person		
ANSWER	COUNT	PROB
Help	62	0.434
Maybe	30	0.210
Don'k know	12	0.084
Maybe no	9	0.063
Don't help	30	0.210
TOT	143	1

Positive	0.434
Positive + Maybe	0.643

W vector evaluation

W=

Intervals			Qn.
0.951	0.965	Do you look for your missing relative/friend?	17
0.825	0.881	Do you follow the group of people?	18
0.483	0.769	Do you help a not seriously injured person?	19
0.434	0.643	Do you help a seriously injured person?	20

Wavg=

		Qn.
0.958	Do you look for your missing relative/friend?	17
0.853	Do you follow the group of people?	18
0.626	Do you help a not seriously injured person?	19
0.538	Do you help a seriously injured person?	20

S*Wavg
0.842
0.747
0.540
0.460

Wavg-S*Wavg
0.116
0.107
0.086
0.078

T matrix			
0.142	-0.010	-0.010	-0.010
-0.010	0.150	-0.010	-0.010
-0.010	-0.010	0.175	-0.010
-0.010	-0.010	-0.010	0.191

CASE 7
FAMILY
INJURED
SEE EMERGENCY EXIT

QUESTION 21		
Search your relatives?		
ANSWER	COUNT	PROB
Yes	86	0.601
Maybe	27	0.189
Don'k know	10	0.070
Maybe no	15	0.105
No	5	0.035
TOT	143	1

Positive + Maybe	0.790
Positive + Maybe + I don't know	0.860

QUESTION 22		
You see a group running in another direction		
ANSWER	COUNT	PROB
Follow	9	0.063
Maybe	21	0.147
Don'k know	11	0.077
Maybe no	41	0.287
Don't follow	61	0.427
TOT	143	1

Positive + Maybe	0.210
Positive + Maybe + I don't know	0.287

QUESTION 23		
You see a not seriously injured person.		
ANSWER	COUNT	PROB
Help	43	0.301
Maybe	36	0.252
Don'k know	26	0.182
Maybe no	21	0.147
Don't help	17	0.119
TOT	143	1

Positive	0.301
Positive + Maybe	0.552

QUESTION 24		
You see a seriously injured person		
ANSWER	COUNT	PROB
Help	37	0.259
Maybe	28	0.196
Don'k know	18	0.126
Maybe no	8	0.056
Don't help	52	0.364
TOT	143	1

Positive	0.259
Positive + Maybe	0.455

W vector evaluation

W=

Intervals			Qn.
0.790	0.860	Do you look for your missing relative/friend?	21
0.210	0.287	Do you follow the group of people?	22
0.301	0.552	Do you help a not seriously injured person?	23
0.259	0.455	Do you help a seriously injured person?	24

Wavg=

		Qn.
0.825	Do you look for your missing relative/friend?	21
0.248	Do you follow the group of people?	22
0.427	Do you help a not seriously injured person?	23
0.357	Do you help a seriously injured person?	24

	0.732
S*Wavg	0.207
	0.370
	0.306

	0.093
Wavg-S*Wavg	0.041
	0.057
	0.051

T matrix			
0.125	-0.010	-0.010	-0.010
-0.010	0.230	-0.010	-0.010
-0.010	-0.010	0.167	-0.010
-0.010	-0.010	-0.010	0.184

CASE 8
FAMILY
INJURED
DON'T SEE EMERGENCY EXIT

QUESTION 25		
Search your relatives?		
ANSWER	COUNT	PROB
Yes	86	0.601
Maybe	29	0.203
Don'k know	8	0.056
Maybe no	13	0.091
No	7	0.049
TOT	143	1

Positive + Maybe	0.804
Positive + Maybe + I don't know	0.860

QUESTION 26		
You see a group running in another direction		
ANSWER	COUNT	PROB
Follow	46	0.322
Maybe	72	0.503
Don'k know	8	0.056
Maybe no	8	0.056
Don't follow	9	0.063
TOT	143	1

Positive + Maybe	0.825
Positive + Maybe + I don't know	0.881

QUESTION 27		
You see a not seriously injured person.		
ANSWER	COUNT	PROB
Help	41	0.287
Maybe	36	0.252
Don'k know	31	0.217
Maybe no	14	0.098
Don't help	21	0.147
TOT	143	1

Positive	0.287
Positive + Maybe	0.538

QUESTION 28		
You see a seriously injured person		
ANSWER	COUNT	PROB
Help	35	0.245
Maybe	24	0.168
Don'k know	27	0.189
Maybe no	8	0.056
Don't help	49	0.343
TOT	143	1

Positive	0.245
Positive + Maybe	0.413

W vector evaluation

	Intervals			Qn.
	0.804	0.860	Do you look for your missing relative/friend?	25
	0.825	0.881	Do you follow the group of people?	26
W=	0.287	0.538	Do you help a not seriously injured person?	27
	0.245	0.413	Do you help a seriously injured person?	28

			Qn.
	0.832	Do you look for your missing relative/friend?	25
	0.853	Do you follow the group of people?	26
Wavg=	0.413	Do you help a not seriously injured person?	27
	0.329	Do you help a seriously injured person?	28

	0.733
S*Wavg	0.752
	0.351
	0.275

	0.099
Wavg-S*Wavg	0.101
	0.061
	0.054

T matrix			
0.138	-0.010	-0.010	-0.010
-0.010	0.137	-0.010	-0.010
-0.010	-0.010	0.198	-0.010
-0.010	-0.010	-0.010	0.228

Appendix D

Structural Analysis Results

Tables in the following pages report the structural analysis results from the model that has been evaluated by the Pacific Earthquake Engineering Research Center (PEER) in terms of:

- Peak story drifts [%].
- Peak story accelerations [m/s^2] (including base floor acceleration).
- Residual story drifts[%].
- Story velocities [m/s].
- Corresponding frequencies [Hz], obtained through Fast Fourier Transformation.

Story Drift (%)

	GM factor	GM Number / Sa Tm=2.5 sec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Peak First Story Drift	0.3	0.15	0.8692	0.8222	0.5357	0.7159	0.5986	0.5568	0.6071	0.6097	0.8292	0.6854	0.7979	0.6662	0.7047	0.6327	0.6739	0.8166
	0.4	0.2	0.9351	0.9133	0.5182	0.8027	0.6515	0.6465	0.7406	0.6110	0.8695	0.7628	0.8714	0.6671	0.7234	0.6545	0.6795	0.8608
	0.5	0.25	1.0254	0.9784	0.5421	0.7836	0.7011	0.6678	0.8586	0.6726	0.9082	0.8386	0.9071	0.7543	0.7786	0.6806	0.8436	0.8852
	0.6	0.3	1.0645	1.0524	0.6676	0.8149	0.7636	0.7216	0.9226	0.7594	0.9461	0.9124	0.9074	0.8342	0.8416	0.7241	0.8827	0.9075
	0.7	0.35	1.1654	1.1016	0.8055	0.9159	0.9739	0.9225	1.0514	0.7695	0.9887	0.9899	0.9075	0.8770	0.8850	0.7965	0.9143	0.9346
	0.8	0.4	1.2830	1.1373	0.9542	1.0219	1.1701	1.1566	1.4944	0.7913	1.0294	1.0743	0.9124	0.9108	0.9461	0.8002	0.9449	0.9511
	0.9	0.45	1.4821	1.1757	1.1166	7.0469	1.5644	3.3764	6.6630	0.7953	1.0589	1.1568	0.9417	0.8961	0.9819	0.8489	0.9905	0.9776
	1	0.5	1.7840	1.2198	1.3250	4.9266	2.5737	3.7507	9.5002	0.8030	3.9924	1.2139	1.0059	0.9295	1.0370	0.9013	1.0649	0.9996
	1.1	0.55	2.8863	1.2413	2.5288	3.9547	4.2083	6.8456	11.7986	0.8193	6.0681	1.2709	1.0661	0.9496	1.0579	0.9979	1.1546	1.0321
	1.2	0.6	10.8065	1.2696	3.9184	10.0888	7.8497	12.8180	11.1741	0.9003	15.6320	1.3568	1.1207	0.9707	1.0756	1.2934	1.2725	1.1353

	GM factor	GM Number / Sa Tm=2.5 sec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Peak First Story Drift	0.3	0.15	1.3370	1.2435	0.6563	0.9377	0.8202	0.8132	0.8109	0.8061	1.2664	0.9550	1.1771	0.9531	1.0184	0.7600	0.9140	1.1176
	0.4	0.2	1.4479	1.4524	0.6472	1.1088	0.9008	0.8984	1.0191	0.8488	1.3561	1.0584	1.2921	0.9598	1.0836	0.7872	1.0842	1.1801
	0.5	0.25	1.5980	1.5883	0.6519	1.1016	0.9668	0.9690	1.1694	0.9478	1.4203	1.1569	1.3643	1.0709	1.1429	0.8135	1.1850	1.2091
	0.6	0.3	1.6465	1.7163	0.7914	1.0790	1.0299	1.0155	1.2437	1.0817	1.4620	1.2527	1.3371	1.1642	1.2663	0.9173	1.2018	1.2198
	0.7	0.35	1.7763	1.7826	0.9867	1.1180	1.2618	1.1151	1.3199	1.1117	1.5095	1.3530	1.3272	1.2988	1.3740	0.9974	1.2280	1.2415
	0.8	0.4	1.9125	1.8222	1.1836	1.2530	1.4938	1.3843	1.6521	1.0970	1.5571	1.4585	1.3049	1.4238	1.4872	0.9363	1.2543	1.2383
	0.9	0.45	2.0780	1.8606	1.3966	6.1393	1.7720	3.1693	6.3876	1.0754	1.5778	1.5481	1.3301	1.4220	1.5246	1.0516	1.3126	1.2537
	1	0.5	2.2462	1.9012	1.6261	4.3802	2.6448	4.2382	9.3859	1.0746	3.4992	1.5870	1.3533	1.4221	1.5321	1.1748	1.3814	1.3271
	1.1	0.55	3.0055	1.9105	2.6709	3.6256	5.0871	7.8752	11.0556	1.1112	5.0605	1.6190	1.3894	1.4861	1.5381	1.3085	1.5115	1.4765
	1.2	0.6	9.8421	1.9247	4.1141	7.3072	8.4357	13.0461	10.3410	1.1993	11.0811	1.6697	1.4528	1.5443	1.6384	1.4538	1.6678	1.6064

	GM factor	GM Number / Sa Tm=2.5 sec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Peak Third Story Drift	0.3	0.15	1.5384	1.5113	0.7230	1.3217	0.8963	0.9660	0.9606	0.8464	1.4620	1.0403	1.2823	1.0569	1.1588	0.7909	1.1423	1.1801
	0.4	0.2	1.7153	1.7563	0.6471	1.3714	0.9976	0.9935	1.0997	0.9122	1.5930	1.1577	1.5431	1.1003	1.2661	0.8092	1.2619	1.2409
	0.5	0.25	1.8610	1.8952	0.6528	1.3461	1.0671	1.1163	1.1761	1.0326	1.6796	1.2635	1.6303	1.2045	1.3569	0.9324	1.2274	1.2503
	0.6	0.3	1.9656	2.0521	0.8016	1.3379	1.1319	1.2107	1.2275	1.1837	1.7021	1.3538	1.5793	1.3161	1.4804	1.1513	1.2176	1.2803
	0.7	0.35	2.0453	2.1251	1.0097	1.2955	1.2636	1.1428	1.2837	1.2327	1.7225	1.4445	1.5631	1.4705	1.6569	1.2042	1.2274	1.3090
	0.8	0.4	2.1122	2.1612	1.1917	1.4689	1.4301	1.2706	1.4212	1.2480	1.7460	1.5353	1.5170	1.6609	1.7441	0.9958	1.2387	1.3403
	0.9	0.45	2.1995	2.1865	1.3712	7.9185	1.5936	3.0835	7.4038	1.2209	1.7396	1.6034	1.3992	1.6700	1.7807	1.1112	1.3179	1.3721
	1	0.5	2.2671	2.2080	1.5468	5.3208	2.4178	4.4837	9.8544	1.2174	3.8668	1.6126	1.4298	1.6754	1.8985	1.2386	1.4331	1.4900
	1.1	0.55	3.5573	2.1935	2.8326	3.7099	5.3178	8.3959	10.4733	1.2496	6.0325	1.6130	1.5078	1.7412	2.1055	1.3736	1.5558	1.6188
	1.2	0.6	11.0206	2.1819	4.8083	8.8626	9.0284	12.1768	9.3397	1.4226	11.0130	1.6203	1.5739	1.8127	2.2743	1.5542	1.6969	1.7114

Story Acceleration (m/s^2)

		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Peak Base Story Acc.	GM factor	Sa Tm=2.5 sec																
	0.3	0.15	4.95	4.20	3.60	5.07	3.07	5.41	2.92	4.01	4.24	2.11	6.17	3.99	5.49	6.54	2.77	5.02
	0.4	0.2	5.03	4.44	5.05	5.03	3.59	5.77	3.66	5.37	4.88	2.82	7.32	4.40	6.36	6.53	4.74	5.80
	0.5	0.25	5.93	5.61	4.75	5.64	3.95	6.01	4.69	5.93	6.23	3.38	6.76	4.93	6.76	6.65	4.76	6.02
	0.6	0.3	6.83	6.11	5.71	6.01	4.38	6.30	6.05	6.09	7.54	3.53	7.63	5.99	7.12	6.66	5.05	6.66
	0.7	0.35	7.66	6.36	4.79	6.81	4.89	6.51	6.60	6.92	8.77	3.73	9.43	5.75	7.45	7.37	5.54	7.27
	0.8	0.4	8.41	6.63	5.85	8.10	5.67	6.74	22.71	7.41	10.01	3.98	7.80	6.17	7.71	7.97	5.80	7.50
	0.9	0.45	9.12	8.26	6.61	598.71	6.05	285.60	605.81	7.82	11.25	4.11	8.65	6.63	8.15	8.29	6.39	7.89
	1	0.5	9.77	8.44	6.54	497.72	160.13	285.56	711.27	8.07	468.33	5.70	9.64	7.08	8.76	8.47	6.54	8.57
	1.1	0.55	140.65	9.35	243.02	294.25	411.70	601.85	589.84	8.16	631.23	6.02	10.19	7.34	8.85	8.30	6.62	9.33
	1.2	0.6	329.97	9.98	212.41	1017.38	685.75	789.84	721.77	8.46	1511.70	6.09	10.92	7.83	9.12	63.06	6.71	10.10
		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Peak First Story Acc.	GM factor	Sa Tm=2.5 sec																
	0.3	0.15	3.98	2.91	2.35	4.20	2.76	2.18	2.19	2.25	3.75	1.49	3.59	2.85	2.98	2.04	2.22	3.54
	0.4	0.2	5.05	3.50	2.95	5.25	3.47	2.64	2.59	2.99	5.05	1.79	4.70	3.51	3.89	2.57	2.56	4.33
	0.5	0.25	5.76	4.10	3.62	5.58	4.01	2.99	2.80	3.35	6.29	2.19	5.22	4.04	4.32	3.14	3.00	5.30
	0.6	0.3	5.92	4.66	3.66	5.84	4.60	3.47	3.01	3.95	7.49	2.33	5.64	4.46	4.74	3.51	2.93	6.22
	0.7	0.35	6.81	5.22	3.87	6.85	5.15	3.95	3.14	4.34	8.68	2.51	6.52	4.84	5.15	4.39	3.19	7.08
	0.8	0.4	7.97	6.00	4.20	7.90	5.78	4.08	3.61	5.30	9.85	2.72	7.33	5.33	5.47	4.14	3.60	7.87
	0.9	0.45	9.04	6.73	4.75	25.16	6.28	8.89	15.41	5.78	11.02	2.94	8.11	5.75	5.84	3.54	3.98	8.57
	1	0.5	10.02	7.29	5.36	18.29	6.75	9.39	21.36	6.23	23.16	3.09	8.80	6.19	6.18	3.09	4.32	9.25
	1.1	0.55	15.00	7.80	7.18	14.63	15.93	19.31	16.32	6.67	20.99	3.53	9.64	6.62	6.49	3.56	4.69	9.90
	1.2	0.6	21.81	8.29	14.73	29.50	25.46	25.34	16.07	7.08	46.81	3.57	10.53	7.03	6.79	4.20	5.01	10.55
		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Peak Second Story Acc.	GM factor	Sa Tm=2.5 sec																
	0.3	0.15	4.44	3.07	2.73	4.43	2.24	2.34	1.56	1.99	4.15	1.26	2.74	2.11	2.98	2.27	2.06	4.60
	0.4	0.2	5.44	3.62	3.22	4.96	2.98	2.70	2.10	2.69	5.11	1.54	3.56	2.54	3.53	2.67	2.33	5.61
	0.5	0.25	6.46	4.18	3.60	5.65	3.66	3.01	2.60	3.40	6.17	1.88	3.89	2.66	3.88	3.04	2.63	6.05
	0.6	0.3	7.40	4.67	3.89	6.12	4.34	3.24	3.12	4.03	7.25	2.03	4.72	2.78	4.21	3.18	3.28	6.36
	0.7	0.35	8.31	5.17	4.20	6.77	4.93	3.61	3.65	4.42	8.36	2.16	5.81	3.09	4.53	3.46	3.81	6.72
	0.8	0.4	9.22	5.71	4.75	7.47	5.43	4.06	3.99	4.45	9.45	2.29	6.74	3.39	4.85	3.73	4.17	7.06
	0.9	0.45	10.10	6.44	5.32	10.48	5.83	8.19	10.43	4.55	10.53	2.48	7.40	3.67	5.17	3.91	4.23	7.43
	1	0.5	11.06	7.13	5.84	16.40	6.77	6.09	10.06	4.68	14.58	2.66	8.05	4.08	5.49	4.30	4.31	7.88
	1.1	0.55	12.13	7.85	6.29	15.35	6.64	9.90	10.85	5.00	17.09	2.98	8.75	4.50	5.81	4.73	4.33	8.37
	1.2	0.6	15.74	8.62	6.66	16.04	9.55	10.40	10.87	5.39	17.27	3.04	9.42	4.84	6.13	5.15	4.37	8.80
		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Peak Third Story Acc.	GM factor	Sa Tm=2.5 sec																
	0.3	0.15	5.00	4.00	2.61	3.80	2.44	2.60	2.20	2.65	4.07	2.41	4.35	2.52	3.52	2.22	3.01	3.04
	0.4	0.2	6.12	4.69	2.92	4.29	2.85	3.03	2.60	3.36	4.91	2.68	5.36	3.09	4.15	2.47	3.24	3.27
	0.5	0.25	6.98	5.45	3.27	4.95	3.15	3.20	2.84	3.87	5.92	2.92	5.81	3.61	4.58	2.71	3.14	3.44
	0.6	0.3	7.56	6.00	3.99	5.63	3.48	3.75	3.01	4.37	6.94	3.12	6.17	3.99	4.82	3.17	3.14	4.02
	0.7	0.35	8.06	6.65	4.98	6.40	4.08	3.91	3.17	4.82	8.00	3.29	6.56	4.28	4.91	3.39	3.19	4.46
	0.8	0.4	8.54	6.93	5.62	7.26	4.41	4.01	3.88	5.27	9.05	3.46	6.91	4.52	5.14	3.71	3.51	4.81
	0.9	0.45	9.01	7.36	6.26	8.44	4.75	5.60	5.64	5.39	10.11	3.63	7.22	4.73	5.50	4.06	3.81	5.21
	1	0.5	9.75	7.87	6.73	7.97	5.15	5.08	6.42	5.49	11.32	3.66	7.58	5.08	6.22	4.44	4.05	5.98
	1.1	0.55	10.83	8.43	7.04	7.90	6.41	5.81	5.69	5.58	12.19	3.73	8.01	5.53	6.90	4.80	4.29	6.73
	1.2	0.6	10.60	9.04	7.18	10.08	7.58	6.40	6.01	5.66	17.22	3.67	8.68	5.94	7.51	5.19	4.53	7.55

Residual Story Drift(%)

	GM factor	GM Number / Sa Tm=2.5 sec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Residual First Story Drift	0.3	0.15	0.10910	-0.08428	0.00408	0.06686	0.01212	0.02049	0.01293	-0.17774	-0.10302	-0.09406	0.12887	-0.02691	-0.18353	0.01528	0.03914	0.02406
	0.4	0.2	0.12500	-0.10451	0.00572	0.08647	0.01584	0.02653	0.01805	-0.23048	-0.12562	-0.11786	0.16402	0.03525	-0.24387	0.02051	0.05266	0.03244
	0.5	0.25	0.12654	-0.09430	0.00587	0.11119	0.02032	0.03261	0.02517	-0.25603	-0.15124	-0.14763	0.20018	0.10046	-0.26205	0.02563	0.06534	0.04116
	0.6	0.3	0.12739	-0.07439	0.00676	0.14019	0.02377	0.03817	0.03219	-0.26105	-0.16636	-0.18487	0.24318	0.14991	-0.22478	0.03072	0.07315	0.04889
	0.7	0.35	0.11169	-0.04577	0.00420	0.16313	0.02630	0.04513	0.02910	-0.27029	-0.17652	-0.22877	0.27808	0.14672	-0.18348	0.03513	0.07872	0.05704
	0.8	0.4	0.09226	-0.03093	0.00376	0.17284	0.02425	0.08649	-0.13080	-0.28675	-0.18059	-0.27733	0.30332	0.14679	-0.14627	0.04088	0.08342	0.06479
	0.9	0.45	0.07236	-0.01693	0.02815	-5.12155	0.04153	1.54075	-4.98608	-0.27996	-0.18399	-0.30831	0.31800	0.12415	-0.10728	0.04648	0.08288	0.07296
	1	0.5	-0.00110	0.01185	0.10137	-2.69521	0.44120	1.94883	-7.92429	-0.26621	-1.84811	-0.33304	0.33884	0.08180	-0.08732	0.05256	0.07595	0.07589
	1.1	0.55	1.22576	0.07540	0.92426	-0.08215	2.53695	5.40419	-10.06880	-0.20825	-3.66943	-0.35970	0.36691	0.05516	-0.07968	0.05964	0.05860	0.07187
	1.2	0.6	9.77121	0.17925	2.25564	-8.42112	6.52595	11.82040	-9.29269	-0.15135	-2.02523	-0.38442	0.39423	0.03210	-0.08354	0.01686	0.01810	0.05946

	GM factor	GM Number / Sa Tm=2.5 sec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Residual Second Story Drift	0.3	0.15	0.13086	-0.12206	0.00554	0.08716	0.01628	0.02739	0.01727	-0.23502	-0.12548	-0.12022	0.16731	-0.02467	-0.24408	0.02035	0.05150	0.03273
	0.4	0.2	0.15108	-0.16592	0.00767	0.11150	0.02126	0.03532	0.02437	-0.30501	-0.15048	-0.15116	0.20612	0.04967	-0.32370	0.02722	0.06637	0.04320
	0.5	0.25	0.15449	-0.16081	0.00784	0.14354	0.02739	0.04309	0.03535	-0.33905	-0.18014	-0.19166	0.24937	0.12315	-0.34951	0.03397	0.08211	0.05531
	0.6	0.3	0.16551	-0.14021	0.00898	0.18191	0.03260	0.04956	0.04627	-0.34624	-0.19944	-0.24422	0.31069	0.17486	-0.30558	0.04073	0.09277	0.06438
	0.7	0.35	0.15197	-0.10262	0.00557	0.21203	0.03547	0.05873	0.04413	-0.35890	-0.21035	-0.30656	0.35766	0.17163	-0.26019	0.04633	0.10008	0.07438
	0.8	0.4	0.13852	-0.08019	0.00552	0.21725	0.02612	0.10524	-0.06896	-0.37851	-0.21216	-0.37342	0.39444	0.18798	-0.20136	0.05420	0.10684	0.08319
	0.9	0.45	0.14338	-0.06293	0.04080	-4.28337	0.05224	1.31294	-4.55345	-0.36808	-0.21794	-0.41094	0.41818	0.16546	-0.14789	0.06194	0.10604	0.09118
	1	0.5	0.10118	-0.02411	0.10578	-2.17542	0.49001	2.03210	-7.67077	-0.35188	-1.67674	-0.43130	0.44812	0.12319	-0.11651	0.07232	0.09612	0.08871
	1.1	0.55	1.24899	0.05628	0.86198	0.08958	2.66336	5.49722	-9.29721	-0.27781	-3.11858	-0.45393	0.48779	0.10543	-0.09676	0.08604	0.07369	0.07618
	1.2	0.6	8.92404	0.17429	2.23100	-5.42844	6.46557	11.33160	-8.43081	-0.19864	-3.12252	-0.47047	0.52133	0.08967	-0.09878	0.07879	0.03390	0.05846

	GM factor	GM Number / Sa Tm=2.5 sec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Residual Third Story Drift	0.3	0.15	0.1370	-0.1268	0.0058	0.0885	0.0170	0.0284	0.0176	-0.2410	-0.1271	-0.1184	0.1704	-0.0053	-0.2498	0.0211	0.0520	0.0332
	0.4	0.2	0.1685	-0.1813	0.0080	0.1136	0.0221	0.0366	0.0247	-0.3128	-0.1506	-0.1485	0.2067	0.0608	-0.3315	0.0281	0.0665	0.0429
	0.5	0.25	0.1823	-0.1832	0.0081	0.1467	0.0284	0.0446	0.0347	-0.3482	-0.1780	-0.1882	0.2488	0.1137	-0.3586	0.0351	0.0835	0.0548
	0.6	0.3	0.2025	-0.1711	0.0093	0.1862	0.0337	0.0511	0.0438	-0.3559	-0.1987	-0.2388	0.3141	0.1409	-0.3155	0.0420	0.0950	0.0634
	0.7	0.35	0.1952	-0.1364	0.0058	0.2170	0.0369	0.0592	0.0487	-0.3693	-0.2107	-0.2973	0.3617	0.1364	-0.2728	0.0479	0.1032	0.0731
	0.8	0.4	0.1852	-0.1129	0.0034	0.2181	0.0307	0.0899	-0.0077	-0.3876	-0.2131	-0.3579	0.3997	0.1654	-0.1874	0.0559	0.1113	0.0818
	0.9	0.45	0.2066	-0.0956	0.0281	-4.5220	0.0566	1.0738	-4.6301	-0.3743	-0.2218	-0.3891	0.4249	0.1567	-0.1273	0.0637	0.1134	0.0889
	1	0.5	0.1830	-0.0557	0.0725	-2.1695	0.4551	1.9864	-7.3339	-0.3600	-1.5611	-0.4048	0.4547	0.1354	-0.0939	0.0745	0.1080	0.0866
	1.1	0.55	1.2639	0.0225	0.7552	0.1163	2.6394	5.5215	-8.4276	-0.2882	-2.9144	-0.4244	0.4931	0.1412	-0.0712	0.0890	0.0911	0.0749
	1.2	0.6	8.8744	0.1297	2.2673	-4.7401	6.5426	9.7022	-7.4481	-0.2068	-5.4838	-0.4384	0.5273	0.1504	-0.0688	0.1030	0.0598	0.0600

Story Velocity (m/s)

	FN component	Original Number	1	4	6	7	12	13	15	20	23	25	26	29	33	34	35	36
Peak Base Story Velocity		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	GM factor	Sa Tm=2.5 sec																
	0.3	0.15	0.3504	0.2724	0.7896	0.5362	0.7847	0.4446	0.5049	0.4513	0.3774	0.3226	0.3835	0.2308	0.2755	0.4243	0.3350	0.3967
	0.4	0.2	0.4546	0.3401	0.9761	0.6634	1.0481	0.5934	0.7111	0.5906	0.4920	0.3876	0.4480	0.2797	0.3398	0.4640	0.3826	0.4719
	0.5	0.25	0.5393	0.4204	1.1359	0.7880	1.3117	0.6935	0.9099	0.6981	0.6063	0.4290	0.5231	0.3180	0.4183	0.5533	0.4661	0.5600
	0.6	0.3	0.6182	0.5497	1.2946	0.9146	1.5618	0.7969	1.1175	0.7800	0.7396	0.4669	0.6059	0.3854	0.5056	0.6697	0.5722	0.6187
	0.7	0.35	0.7896	0.6875	1.4500	1.0560	1.7673	0.9002	1.3197	0.8590	0.8765	0.5058	0.6688	0.4164	0.5868	0.7855	0.6803	0.6676
	0.8	0.4	0.9537	0.8068	1.6127	1.2700	1.9551	1.1231	1.5189	0.9335	1.0111	0.5568	0.7330	0.4438	0.6639	0.9010	0.7889	0.7054
	0.9	0.45	1.1125	0.9078	1.8189	1.7474	2.1436	1.3085	1.7147	0.9998	1.1432	0.6204	0.8054	0.4697	0.7474	1.0165	0.8861	0.7327
	1	0.5	1.2713	1.0072	2.0192	1.9073	2.3328	1.3535	1.9109	1.0665	1.9552	0.6621	0.8738	0.4946	0.8157	1.1322	0.9690	0.7566
	1.1	0.55	1.4388	1.0907	2.2461	1.9749	2.5206	1.3062	2.1615	1.1449	2.2119	0.7011	0.9205	0.5170	0.8697	1.2511	1.0442	0.8293
	1.2	0.6	1.9559	1.1750	2.6048	2.3360	2.7077	1.5176	2.3242	1.2205	3.2643	0.7449	0.9757	0.5402	0.9017	1.3687	1.1147	0.9165

	FN component	Orignial Number	1	4	6	7	12	13	15	20	23	25	26	29	33	34	35	36
Peak First Story Velocity		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	GM factor	Sa Tm=2.5 sec																
	0.3	0.15	0.3504	0.2724	0.7896	0.5362	0.7847	0.4446	0.5049	0.4513	0.3774	0.3226	0.3835	0.2308	0.2755	0.4243	0.3350	0.3967
	0.4	0.2	0.4546	0.3401	0.9761	0.6634	1.0481	0.5934	0.7111	0.5906	0.4920	0.3876	0.4480	0.2797	0.3398	0.4640	0.3826	0.4719
	0.5	0.25	0.5393	0.4204	1.1359	0.7880	1.3117	0.6935	0.9099	0.6981	0.6063	0.4290	0.5231	0.3180	0.4183	0.5533	0.4661	0.5600
	0.6	0.3	0.6182	0.5497	1.2946	0.9146	1.5618	0.7969	1.1175	0.7800	0.7396	0.4669	0.6059	0.3854	0.5056	0.6697	0.5722	0.6187
	0.7	0.35	0.7896	0.6875	1.4500	1.0560	1.7673	0.9002	1.3197	0.8590	0.8765	0.5058	0.6688	0.4164	0.5868	0.7855	0.6803	0.6676
	0.8	0.4	0.9537	0.8068	1.6127	1.2700	1.9551	1.1231	1.5189	0.9335	1.0111	0.5568	0.7330	0.4438	0.6639	0.9010	0.7889	0.7054
	0.9	0.45	1.1125	0.9078	1.8189	1.7474	2.1436	1.3085	1.7147	0.9998	1.1432	0.6204	0.8054	0.4697	0.7474	1.0165	0.8861	0.7327
	1	0.9	1.2713	1.0072	2.0192	1.9073	2.3328	1.3535	1.9109	1.0665	1.9552	0.6621	0.8738	0.4946	0.8157	1.1322	0.9690	0.7566
	1.1	0.55	1.4388	1.0907	2.2461	1.9749	2.5206	1.3062	2.1615	1.1449	2.2119	0.7011	0.9205	0.5170	0.8697	1.2511	1.0442	0.8293
	1.2	0.6	1.9559	1.1750	2.6048	2.3360	2.7077	1.5176	2.3242	1.2205	3.2643	0.7449	0.9757	0.5402	0.9017	1.3687	1.1147	0.9165

	FN component	Orignial Number	1	4	6	7	12	13	15	20	23	25	26	29	33	34	35	36
Peak Second Velocity		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	GM factor	Sa Tm=2.5 sec																
	0.3	0.15	0.5029	0.4679	0.8533	0.6453	0.8054	0.5073	0.5490	0.5356	0.6699	0.4918	0.4657	0.3793	0.3553	0.4638	0.4588	0.4807
	0.4	0.2	0.6052	0.5648	1.0063	0.8011	1.0742	0.6780	0.7065	0.6533	0.7749	0.5541	0.5962	0.4280	0.3981	0.5302	0.4903	0.5551
	0.5	0.25	0.6678	0.6473	1.1531	0.9551	1.3346	0.7913	0.8760	0.7285	0.8740	0.5914	0.6772	0.4490	0.4591	0.5818	0.5156	0.6181
	0.6	0.3	0.7431	0.7258	1.3180	1.1022	1.5713	0.9225	1.1244	0.7816	0.9701	0.6311	0.7111	0.5481	0.5276	0.6667	0.6156	0.6636
	0.7	0.35	0.9156	0.8007	1.5401	1.2545	1.7673	1.0442	1.3701	0.8422	1.0655	0.6719	0.7186	0.5569	0.5994	0.7868	0.7432	0.7574
	0.8	0.4	1.1042	0.9224	1.7600	1.4066	1.9489	1.1200	1.6131	0.9006	1.1606	0.7141	0.7602	0.5742	0.6703	0.9077	0.8818	0.7956
	0.9	0.45	1.2910	1.0202	1.9657	1.5827	2.1264	1.3846	1.8530	0.9628	1.2543	0.7577	0.8438	0.6047	0.7132	1.0293	1.0130	0.7971
	1	0.9	1.4743	1.1096	2.1531	2.0715	2.3043	1.3168	2.0870	1.0296	1.9466	0.8010	0.9269	0.6457	0.7579	1.1514	1.1296	0.7925
	1.1	0.55	1.6602	1.1917	2.2033	2.0926	2.4841	1.4056	2.3523	1.1081	2.1551	0.8433	0.9562	0.6860	0.8089	1.2816	1.2211	0.8460
	1.2	0.6	1.8435	1.2821	2.3044	2.1013	2.6648	1.5289	2.4809	1.1846	2.5988	0.8902	1.0099	0.7281	0.8530	1.4185	1.3089	0.9435

	FN component	Orignial Number	1	4	6	7	12	13	15	20	23	25	26	29	33	34	35	36
PeakThird Velocity		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	GM factor	Sa Tm=2.5 sec																
	0.3	0.15	0.8135	0.7088	0.9105	0.7782	0.8488	0.6384	0.5927	0.6193	0.8804	0.6449	0.6419	0.5140	0.5153	0.6683	0.6661	0.5533
	0.4	0.2	1.0262	0.8152	1.0514	1.0062	1.1281	0.7802	0.7195	0.6984	0.9661	0.6772	0.7646	0.5267	0.5239	0.7109	0.6966	0.6540
	0.5	0.25	1.1915	0.9089	1.2844	1.2253	1.3781	0.9313	0.8751	0.7427	1.0638	0.6895	0.8948	0.5929	0.5858	0.7458	0.7291	0.7276
	0.6	0.3	1.2460	1.0011	1.5516	1.4240	1.5936	1.1557	1.1491	0.7755	1.1904	0.7170	0.9811	0.6964	0.6482	0.8044	0.7908	0.7873
	0.7	0.35	1.3059	1.0762	1.8069	1.6224	1.8476	1.3299	1.4209	0.8195	1.3276	0.7653	1.0656	0.7220	0.7092	0.8896	0.9263	0.8433
	0.8	0.4	1.3723	1.1587	2.0492	1.8184	2.0667	1.4675	1.6974	0.8755	1.4825	0.8110	1.1320	0.7529	0.8490	0.9831	1.0705	0.8924
	0.9	0.45	1.4547	1.2521	2.2609	2.0117	2.1849	1.6192	1.9717	0.9578	1.6437	0.8698	1.1189	0.7660	0.9111	1.0968	1.2269	0.9473
	1	0.9	1.5993	1.3509	2.4343	2.2644	2.2770	1.6575	2.2427	1.0452	2.0455	0.9352	1.1168	0.8172	0.9507	1.2184	1.3712	0.9991
	1.1	0.55	1.7992	1.4476	2.6096	2.3479	2.4560	1.5595	2.4715	1.1480	2.1672	0.9982	1.1720	0.8784	1.0181	1.3546	1.4786	1.0684
	1.2	0.6	2.0010	1.5436	2.6912	2.5471	2.6354	1.5290	2.6512	1.2527	2.1885	1.0747	1.2247	0.9383	1.0897	1.4882	1.5799	1.1571

Corresponding Frequency (Hz)

	FN component	Orignial Number	1	4	6	7	12	13	15	20	23	25	26	29	33	34	35	36
		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	GM factor	Sa Tm=2.5 sec																
Peak Base Story Velocity	0.3	0.15	0.14648	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.31738	0.78125	0.36621	0.34180	0.24414	0.36621
	0.4	0.2	0.14648	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.31738	0.36621	0.31738	0.80566	0.36621	0.34180	0.24414	0.36621
	0.5	0.25	0.14648	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.31738	0.36621	0.31738	0.80566	0.36621	0.34180	0.24414	0.36621
	0.6	0.3	0.14648	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.21973	0.31738	0.36621	0.31738	0.24414	0.36621	0.36621	0.24414	0.36621
	0.7	0.35	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.31738	0.24414	0.36621	0.36621	0.24414	0.36621
	0.8	0.4	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.31738	0.24414	0.36621	0.36621	0.24414	0.36621
	0.9	0.45	0.19531	0.21973	0.17090	0.14648	0.24414	0.21973	0.24414	0.29297	0.29297	0.36621	0.31738	0.24414	0.36621	0.36621	0.24414	0.23193
	1	0.5	0.19531	0.21973	0.17090	0.14648	0.24414	0.21973	0.24414	0.29297	0.26855	0.36621	0.34180	0.24414	0.36621	0.36621	0.24414	0.23193
	1.1	0.55	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.26855	0.36621	0.34180	0.24414	0.29297	0.21973	0.24414	0.23193
	1.2	0.6	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	1.41602	0.24414	0.34180	0.24414	0.29297	0.21973	0.24414	0.23193

	FN component	Orignial Number	1	4	6	7	12	13	15	20	23	25	26	29	33	34	35	36
		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	GM factor	Sa Tm=2.5 sec																
Peak First Story Velocity	0.3	0.15	0.63477	0.56152	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.65918	0.36621	0.63477	0.48828	0.36621	0.34180	0.39063	0.52490
	0.4	0.2	0.14648	0.56152	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.65918	0.36621	0.63477	0.41504	0.36621	0.34180	0.39063	0.36621
	0.5	0.25	0.14648	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.73242	0.36621	0.31738	0.41504	0.36621	0.36621	0.24414	0.36621
	0.6	0.3	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.31738	0.36621	0.31738	0.39063	0.36621	0.36621	0.24414	0.36621
	0.7	0.35	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.31738	0.41504	0.36621	0.36621	0.24414	0.36621
	0.8	0.4	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.31738	0.41504	0.36621	0.36621	0.24414	0.36621
	0.9	0.45	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.34180	0.41504	0.36621	0.36621	0.24414	0.23193
	1	0.9	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.34180	0.41504	0.36621	0.36621	0.24414	0.23193
	1.1	0.55	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.26855	0.36621	0.34180	0.41504	0.36621	0.29297	0.24414	0.23193
	1.2	0.6	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.65918	0.36621	0.34180	0.24414	0.29297	0.21973	0.24414	0.23193

	FN component	Orignial Number	1	4	6	7	12	13	15	20	23	25	26	29	33	34	35	36
		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	GM factor	Sa Tm=2.5 sec																
Peak Second Velocity	0.3	0.15	0.63477	0.65918	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.65918	0.63477	0.63477	0.78125	0.65918	0.34180	0.58594	0.57373
	0.4	0.2	0.63477	0.56152	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.65918	0.36621	0.63477	0.78125	0.65918	0.34180	0.58594	0.57373
	0.5	0.25	0.63477	0.56152	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.65918	0.36621	0.63477	0.78125	0.65918	0.36621	0.58594	0.57373
	0.6	0.3	0.19531	0.56152	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.73242	0.36621	0.63477	0.78125	0.36621	0.36621	0.58594	0.36621
	0.7	0.35	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.73242	0.36621	0.31738	0.78125	0.36621	0.36621	0.39063	0.36621
	0.8	0.4	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.73242	0.36621	0.31738	0.41504	0.36621	0.36621	0.24414	0.36621
	0.9	0.45	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.34180	0.41504	0.36621	0.36621	0.24414	0.36621
	1	0.9	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.34180	0.41504	0.36621	0.36621	0.24414	0.23193
	1.1	0.55	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.34180	0.41504	0.36621	0.36621	0.24414	0.23193
	1.2	0.6	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.73242	0.36621	0.34180	0.41504	0.29297	0.29297	0.24414	0.23193

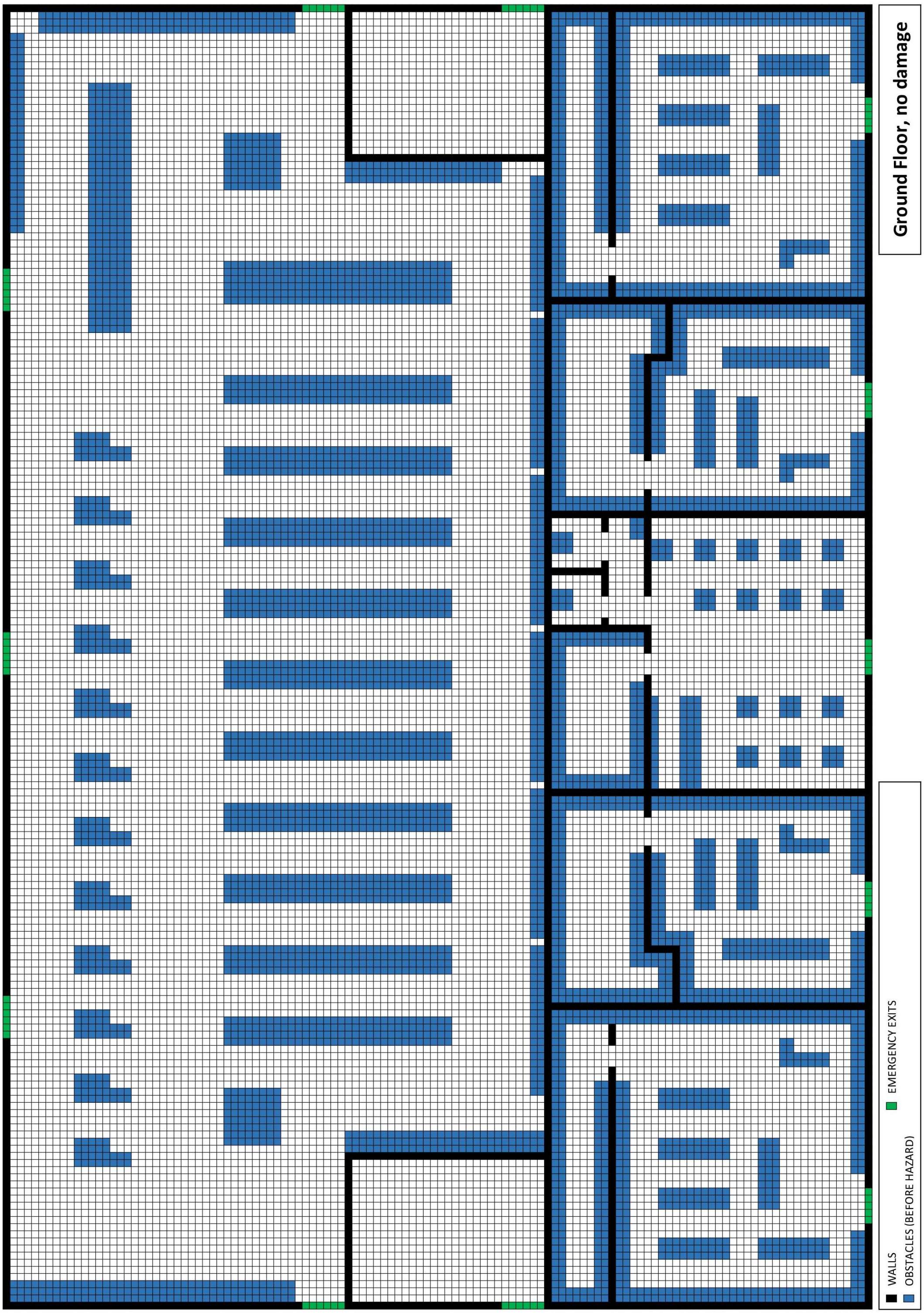
	FN component	Orignial Number	1	4	6	7	12	13	15	20	23	25	26	29	33	34	35	36
		GM Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	GM factor	Sa Tm=2.5 sec																
PeakThird Velocity	0.3	0.15	0.70801	0.65918	0.17090	0.70801	0.26855	0.65918	0.24414	0.53711	0.65918	0.63477	0.63477	0.78125	0.65918	0.34180	0.58594	0.57373
	0.4	0.2	0.63477	0.65918	0.17090	0.70801	0.26855	0.65918	0.24414	0.53711	0.65918	0.63477	0.63477	0.78125	0.65918	0.36621	0.58594	0.57373
	0.5	0.25	0.73242	0.56152	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.65918	0.63477	0.63477	0.78125	0.65918	0.36621	0.58594	0.57373
	0.6	0.3	0.73242	0.56152	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.65918	0.36621	0.63477	0.80566	0.65918	0.36621	0.58594	0.57373
	0.7	0.35	0.73242	0.56152	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.73242	0.36621	0.63477	0.80566	0.36621	0.36621	0.58594	0.57373
	0.8	0.4	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.73242	0.36621	0.34180	0.80566	0.36621	0.36621	0.39063	0.36621
	0.9	0.45	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.73242	0.36621	0.34180	0.80566	0.36621	0.36621	0.24414	0.36621
	1	0.9	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.36621	0.34180	0.80566	0.36621	0.36621	0.24414	0.23193
	1.1	0.55	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.29297	0.39063	0.34180	0.80566	0.36621	0.36621	0.24414	0.23193
	1.2	0.6	0.19531	0.21973	0.17090	0.14648	0.26855	0.21973	0.24414	0.29297	0.73242	0.39063	0.34180	0.80566	0.36621	0.29297	0.24414	0.23193

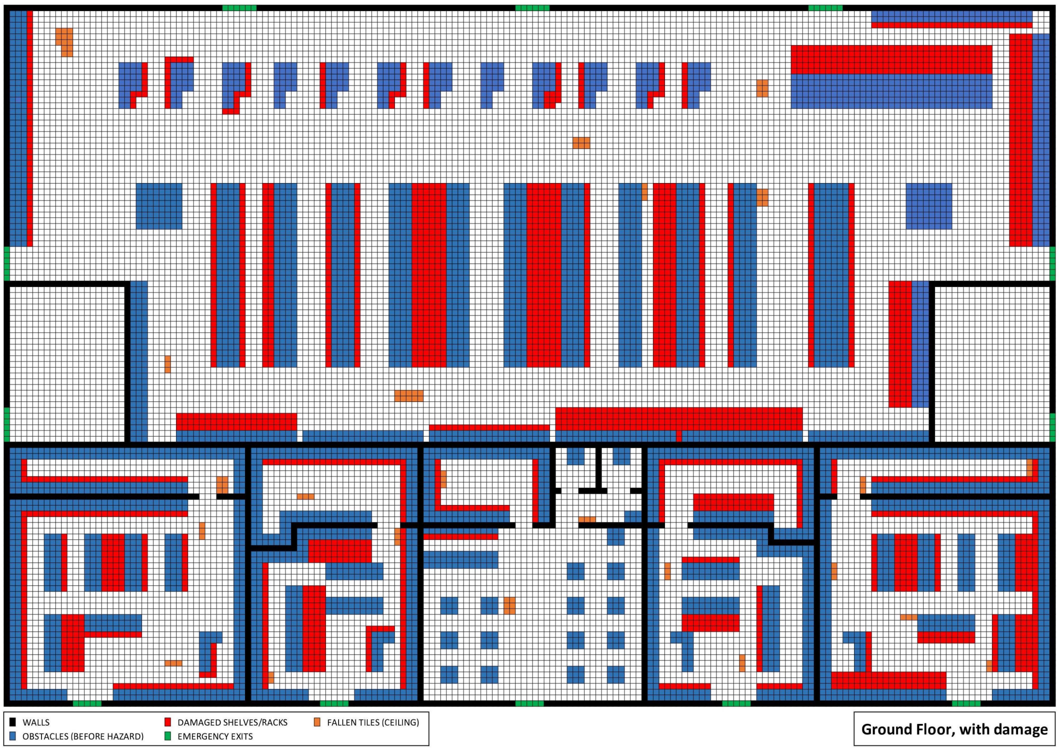
Appendix E

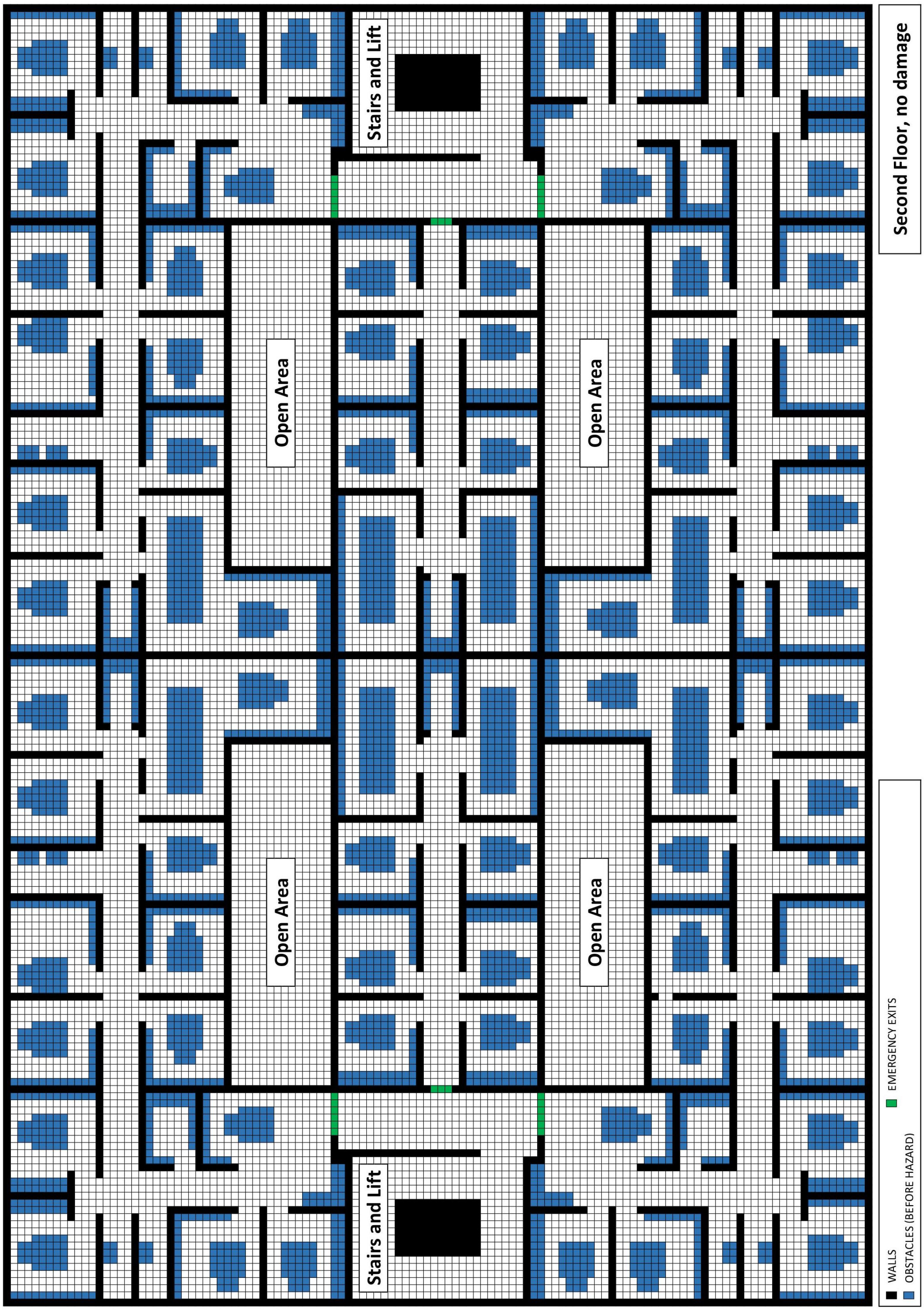
Building Plans

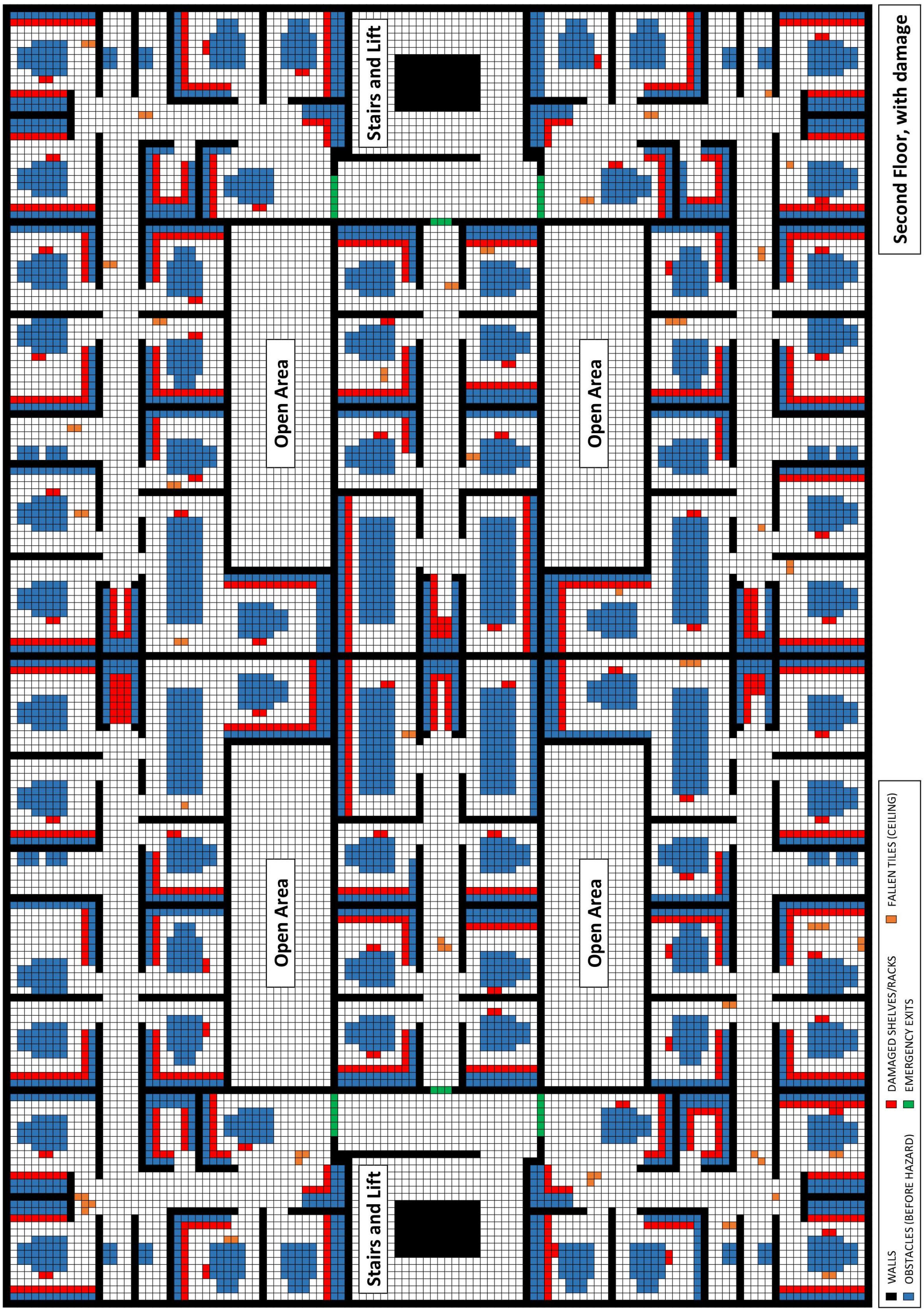
The following images report the plans of all the floors and a ramp of stairs. As reported in the legends:

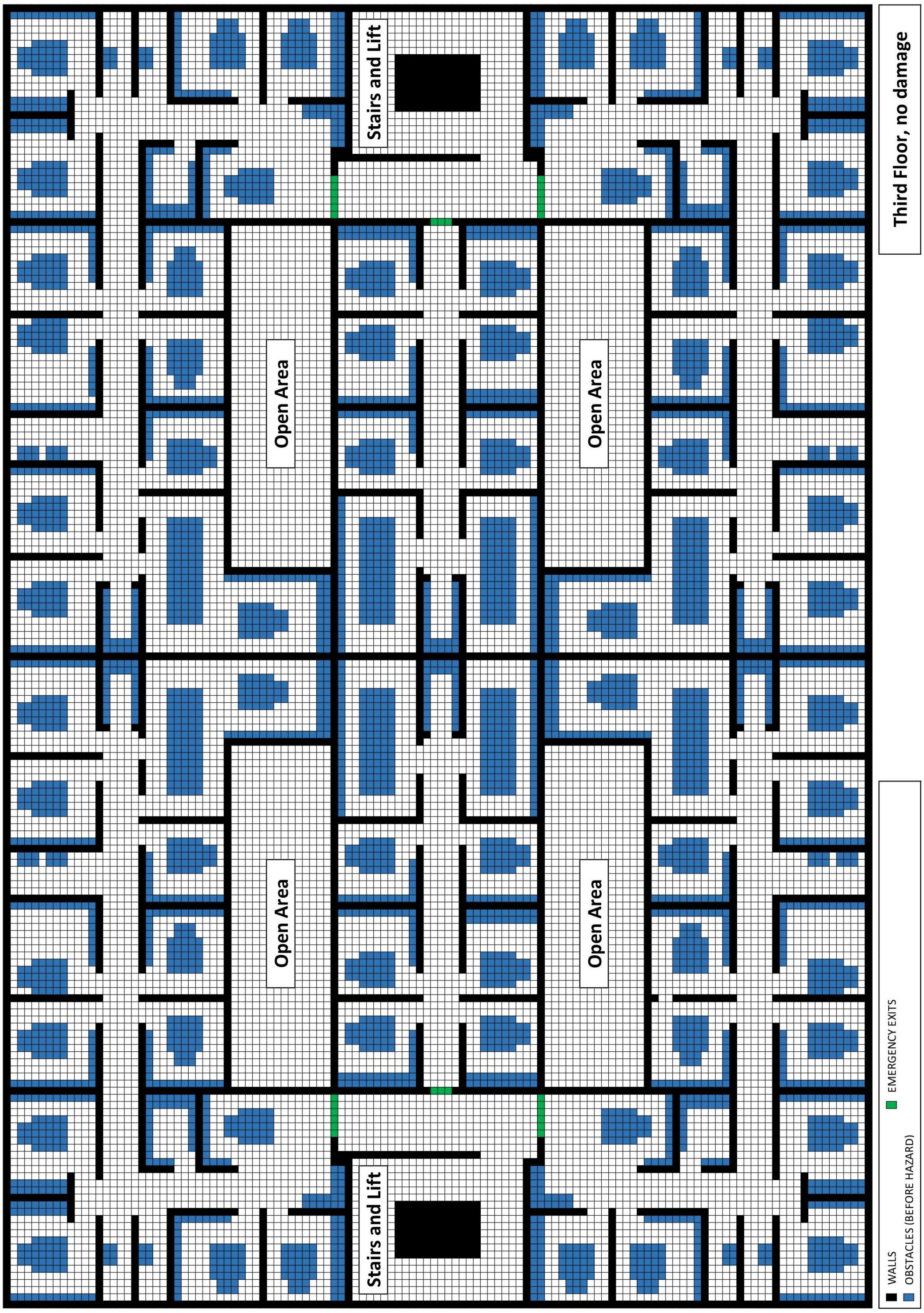
- Green color is used for representing emergency exits.
- Black color is used for representing external and internal walls.
- Blue color is used for representing the obstacles of the undamaged building (shelves, racks, desks and other furniture).
- Red color is used for representing the following new obstacles of the damaged structure: fallen objects from shelves and racks, collapsed shelves and racks, collapsed desktop technologies from desks.
- Orange color is used for representing the collapsed tiles of the ceiling.

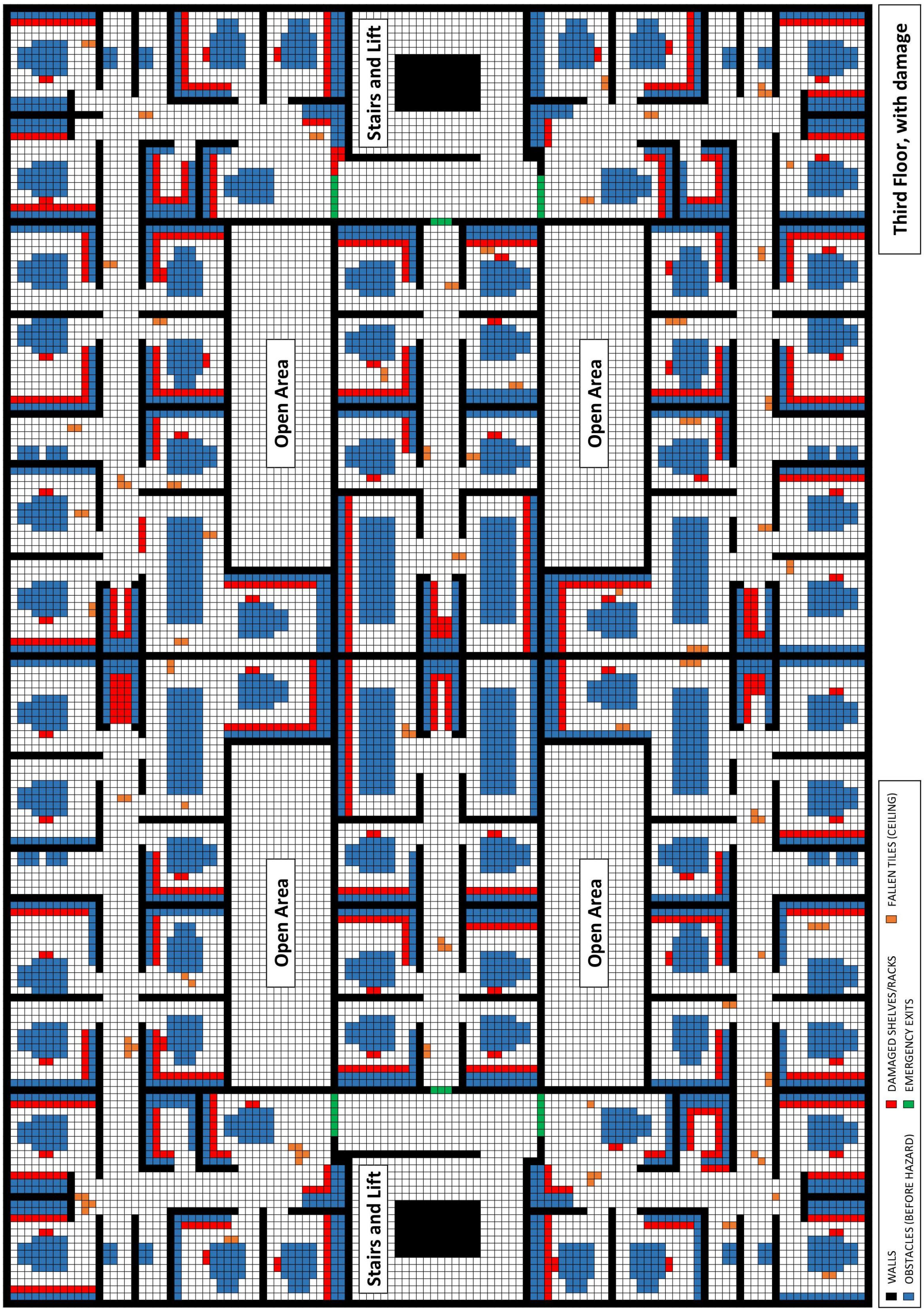

Ground Floor, no damage
WALLS
OBSTACLES (BEFORE HAZARD)
EMERGENCY EXITS


WALLS
OBSTACLES (BEFORE HAZARD)
DAMAGED SHELVES/RACKS
EMERGENCY EXITS
FALLEN TILES (CEILING)
Ground Floor, with damage

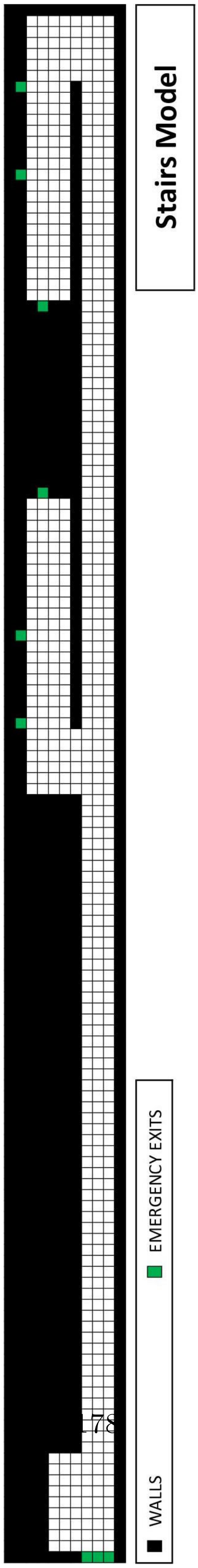

Second Floor, no damage
Stairs and Lift
Open Area
Open Area
Open Area
Open Area
Stairs and Lift
WALLS
OBSTACLES (BEFORE HAZARD)
EMERGENCY EXITS


Second Floor, with damage
Stairs and Lift
Open Area
Open Area
Open Area
Open Area
Stairs and Lift
WALLS
OBSTACLES (BEFORE HAZARD)
DAMAGED SHELVES/RACKS
EMERGENCY EXITS
FALLEN TILES (CEILING)


Stairs and Lift
Open Area
Open Area
Open Area
Open Area
Stairs and Lift
Third Floor, no damage
WALLS
OBSTACLES (BEFORE HAZARD)
EMERGENCY EXITS



Third Floor, with damage
Stairs and Lift
Open Area
Open Area
Open Area
Open Area
Stairs and Lift
WALLS
OBSTACLES (BEFORE HAZARD)
DAMAGED SHELVES/RACKS
EMERGENCY EXITS
FALLEN TILES (CEILING)


Stairs Model
WALLS
EMERGENCY EXITS

This Ph.D. thesis has been typeset by means of the TEX-system facilities. The typesetting engine was pdfLATEX. The document class was `toptesi`, by Claudio Beccari, with option `tipotesi=scudo`. This class is available in every up-to-date and complete TEX-system installation.