ENSURE PROJECT

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ENSURE E-LERNING TOOL

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Tools for vulnerability analysis and representation

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See References in ENSURE Deliverable 3.2

Maps, diagrams and graphs have always been, and continue to be, hard to produce. Initially they were hand drawn, piece-by-piece. Later they were etched on copper-plate and manually colored. Still later, lithography and photo-etching, and most recently, computer software was used, but graphic-makers have always had to struggle with the limitations of available technology—and still do today. Most recently, advances in statistical computation and graphic display have provided tools for visualization of data unthinkable only a half century ago. Similarly, advances in human-computer interaction have created completely new paradigms for exploring information in a dynamic way, with flexible user control, particularly for the display of large networks, hierarchies, data bases, text, and so forth, where problems of very-large scale data present continuing challenges. We can resume visualization tools as following:

Information visualization

Graphs and maps, whether static or dynamic that provides some means to see what lies within, determine the answer to a question, find relations, and perhaps apprehend things which could not be seen so readily in other forms. The term information visualization is generally applied to the visual representation of information.

Scientific visualization

This area is primarily concerned with the visualization of 3-D+ phenomena (architectural, meteorological, medical, biological, etc.), where the emphasis is on realistic renderings of volumes, surfaces, illumination sources, and so forth, perhaps with a dynamic (time) component.

Data visualization

The science of visual representation of “data”, defined as information which has been abstracted in some schematic form, including attributes or variables for the units of information. This topic could be taken to subsume the two main foci: statistical graphics, and thematic cartography. Both of these are concerned with the visual representation of quantitative and categorical data, but driven by different representational goals. Cartographic visualization is primarily concerned with representation constrained to a spatial domain; statistical graphics applies to any domain in which graphical methods are employed in the service of statistical analysis. In addition, cartography and statistical graphics share the common goals of visual representation for exploration and discovery. These range from the simple mapping of locations (urban settlements, rivers, etc.), to spatial distributions of geographic characteristics (species, diseases, ecosystems), to the wide variety of graphic methods used to portray patterns, trends, and indications.

1 An overview of data visualization tools

The graphic representation of quantitative information has deep roots. These roots reach into the history of thematic cartography, statistical graphics, and data visualization, which link one with each other.

In the 18th century, map-makers began to try to show more than just geographical position on a map. Towards the end of this century, the first attempts at the thematic mapping of geologic, economic, and medical data are recorded. As economic and political data began to be collected, some new visual forms were invented to portray them. So, the data could "speak to the eyes".

Over the 19th centuries, numbers pertaining to population (social, medical, and economic statistics) began to be gathered in large and periodic series. Official state statistical offices were established, in recognition of the growing importance of numerical information for social planning, industrialization, commerce, and transportation. The birth of statistical thinking was also accompanied by a rise in visual thinking: diagrams were used to illustrate mathematical functions; various graphic forms were invented to make the properties of empirical numbers– their trends, tendencies, and distributions— more easily communicated, or accessible to visual inspection. Concerning statistical graphics, all modern forms of data display were invented: bar and pie charts, histograms, line graphs, time-series plots, contour plots, etc. In thematic cartography, mapping progressed from single maps to comprehensive atlases, depicting data on a wide variety of topics and wide range of forms of symbolism were introduced.

In the first middle of the 20th century, the enthusiasm for visualization which characterized the late 1800s had been supplanted by the rise of quantification and formal, often statistical, models in the social sciences. Numbers, parameter estimates and indicators were defined. This period is considered as a time of application and popularization, rather than one of innovation. In this period graphical methods were used, perhaps for the first time, to provide new insights, discoveries, and theories in sciences. Graphic innovation was also awaiting new ideas and technology: the development of the machinery of modern statistical methodology, and the advent of the computational power which would support the next wave of developments in data visualization.

Computer processing of data had begun, and offered the possibility to construct old and new graphic forms by computer programs. True high-resolution graphics were developed, but would take a while to enter common use. By the end of this period significant intersections and collaborations would begin: computer science research combine forces with developments in data analysis and display and input technology (pen plotters, graphic terminals, etc.). These developments would provide new paradigms, languages and software packages for expressing and implementing statistical and data graphics. In turn, they would lead to an explosive growth in new visualization methods and techniques. Other themes begin to emerge, mostly as initial suggestions: (a) various visual representations of multivariate data; (b) animations of a statistical process; (c) perceptually based theory (or just informed ideas) related to how graphic attributes and relations might be rendered to better convey the data to the eyes.

It is harder to provide a succinct overview of the most recent developments in data visualization, because they are so varied and across a wider range of disciplines. It is also more difficult to highlight the most significant developments. However, a few major themes could be selected:

- development of a variety of highly interactive computer systems,
- • new paradigms of direct manipulation for visual data analysis (linking, brushing, selection, focusing, etc.)
- • new methods for visualizing high-dimensional data (scatterplot matrix, parallel coordinates plot, etc.);
- • the invention of new graphical techniques for discrete and categorical data (fourfold display, sieve diagram, mosaic plot, etc.), and analogous extensions of older ones (diagnostic plots for generalized linear models, mosaic matrices, etc.) and,
- • the application of visualization methods to an ever-expanding range of substantive problems and data structures.

These developments in visualization methods and techniques arguably depended on advances in theory and technology. Some of these are: (a) software engineering; (b) extensions of classical linear statistical modeling to wider fields; (c) vastly increased computer processing speed and capacity, allowing computationally intensive methods and access to massive data problems.

2 Maps as a basis for spatial vulnerability analysis

Maps are an essential practical tool in any spatial analysis. For identifying the geographical distribution of potential damage, vulnerability mapping is needed. Vulnerability maps attempt to show the spatial or geographical distribution of expected losses from one or more natural hazards. Spatial analysis considers any relevant dangers that have a high correlation with space and it create an abstract, model representation of a territorial reality to serve as a basis for future planning measures.

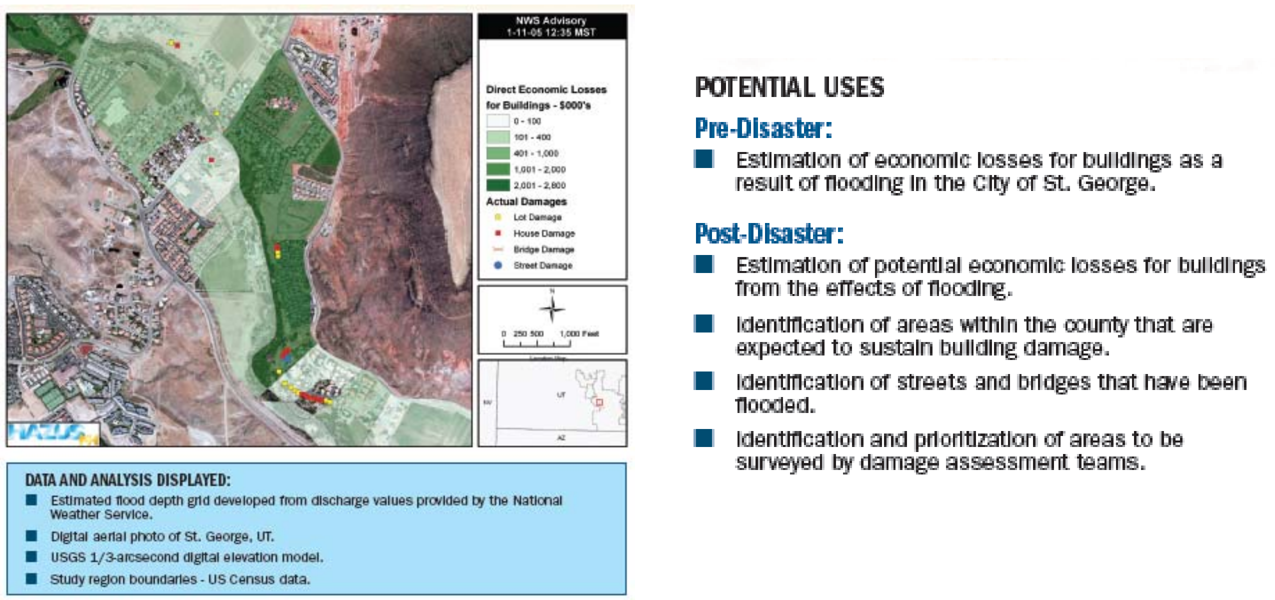
Thorough assessment of the prevailing hazards and risks in a specific region, it is possible to assure any kind of development activity that has a spatial impact. This is particularly important in disaster-prone areas. Those maps contain extensive data of the area in addition of visual information. The appropriate scale of mapping depends both on the use of the maps and the amount of data available.

This allows to have a picture of the situation on the field and to think in which direction to address the efforts for any further action. Vulnerability maps that are based on the measured vulnerability values can be used by politicians, administration, relief organization and operators of critical infrastructures by prioritizing activities and directing financial resources and personnel to the most vulnerable parts of the geographical region and the most vulnerable population subgroups.

As an example of tools for vulnerability mapping, the Federal Emergency Management Agency (USA) develops the methodology HAZUS for analyzing potential losses from floods, hurricanes and earthquakes. The method couple engineering knowledge with the geographic information system (GIS) technology to produce estimates of hazard-related damage before, or after, a disaster occurs. Potential loss estimates analyzed in HAZUS include:

- **Physical damage** to residential and commercial buildings, schools, critical facilities, and infrastructure;
- **Economic loss**, including lost jobs, business interruptions, repair and reconstruction costs; and
- **Social impacts**, including estimates of shelter requirements, displaced households, and population exposed to scenario floods, earthquakes and hurricanes.

Fig. 75 HAZUS application: the example of Santa Clara and Virgin Rivers Floods: the city of Saint George, Utah



2.1 Traditional and innovative tools for vulnerability analysis (PIK)

Visualization is becoming increasingly important in the scientific context. It can be used as well for the exploration of large and complex scientific datasets, the confirmation of hypotheses on the data, and the communication of results. Especially computer supported interactive techniques, allowing the user to directly manipulate the visual representation, can increase the usefulness of visualization in this context.

Sheppard (2005) concludes that the persuasive use of visualizations (in concert with other methods) is justified if they can be effective, and may even be vital in communicating climate change urgently. He suggests various standards that should be adhered to, particularly related to disclosure (i.e., so the content of the visualizations is crystal clear) and defensibility of the methods and data used. As he says, "we should test carefully every potentially powerful weapon in the fight against climate change, especially those which promise rapid results. Visualization tools are potentially too powerful either to be ignored or used without careful consideration." It is hard to disagree with this.

In the context of this deliverable vulnerability is being analysed in the light of its spatial characteristics. It is therefore logic that an obvious tool for vulnerability visualization is the use of maps. Maps have the advantage of presenting data in an easily accessible, readily visible and eye-catching manner.

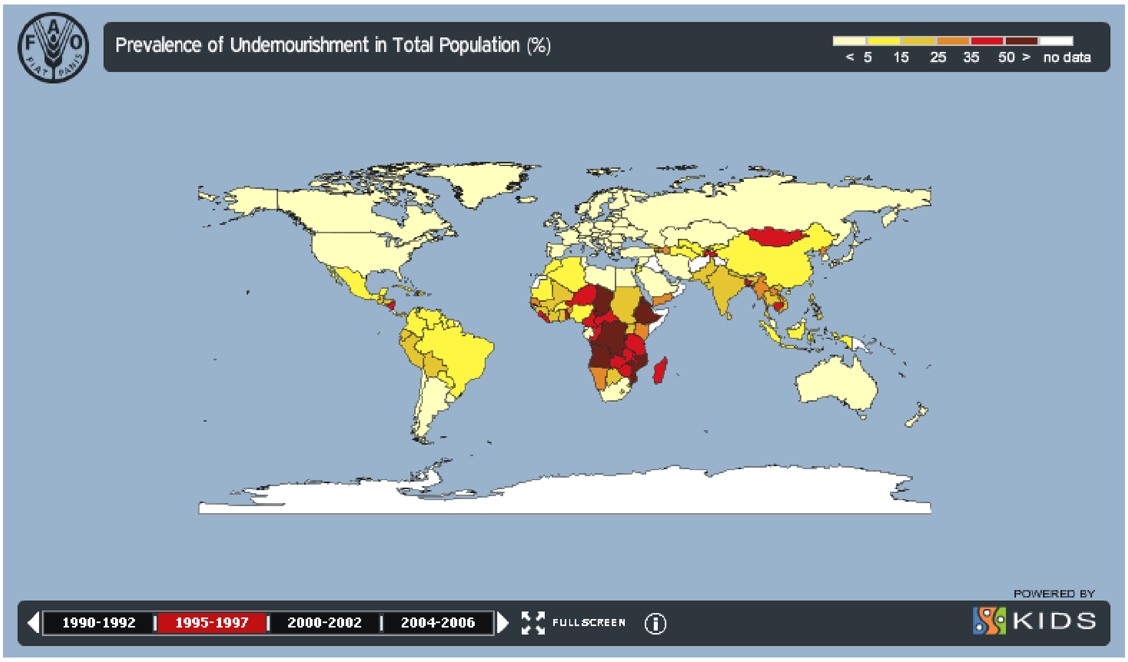
The maps can combine information from different sectors to provide an immediate comprehensive picture of the geographical distribution of vulnerable groups at sub-national level. By providing a visual overview of the major issues affecting vulnerability, the maps highlight gaps and shortfalls in information and thus areas needing attention. The mapping approach for vulnerability visualization has been explored in the context of food-security, some examples:

Food and Agricultural Organization (1998) developed Food Insecurity and Vulnerability Information and Mapping Systems (FIVIMS) that can assemble, analyze and disseminate information about the problem of food insecurity and vulnerability.

Vulnerability analysis and Mapping (VAM) of World Food Programme (1999) prepared composite maps of vulnerability by putting different weights on different indicators. In work related to hurricane Mitch, UNEP-GRID Sioux Falls (1999) prepared an interactive map of Central America showing vulnerability to different natural hazards (http://grid.cr.usgs.gov).

Traditional mapping approaches have the benefit of visualizing data in its geographic context and thus are of great use for dealing with vulnerability information. However, since vulnerability data is typically multivariate, means have to be applied to represent this multidimensional data in an appropriate manner. While geographical maps are the tool of choice to visualize geographic context, several techniques have been developed to generate visual representations of multivariate data, including scatter plots, star plots, parallel coordinates or icons like.

Fig. 2 - GECHS (2000) Project from the University of Victoria used GIS software packages for ranking different countries in terms of a vulnerability index.



The combination of such techniques with maps allows combining the representation of multivariate data in its geographical context. Two approaches can be distinguished. One approach is to locate icons on a map to directly visualize information in its spatial context (e.g. information on a set of cities). Yet, this direct representation of geographic context can only be applied for a limited set of data due to constraints in available screen space.

Thus, a second approach is to combine maps and multivariate representations in a multi view display, using several interlinked representations. Here, the representation of geographic context is given indirectly and thus less intuitive; nevertheless this approach can be used for larger datasets and allows applying all techniques for visualizing multivariate data.

An alternative approach is to reduce the dimensionality of the multivariate data before visualizing it, e.g. to cluster the multivariate information into a number of classes and to represent each class on the map e.g. using a different colour. An example for this approach are the Koeppen climate maps, where multivariate climate information (based on temperature, and precipitation) is mapped into a set of classes can then be represented as grid cells in different colours (Kottek 2006).

We saw that vulnerability is a spatial phenomenon and therefore the use of maps seem to be appropriate to the task of visualizing vulnerability. On the other hand vulnerability is also a concept, which means that it carries many meanings to many different authors. Also here new tools for visualizing vulnerability concepts can come into help. Examples include techniques to visualize tree structures (like Cone Tree or Tree Map), techniques to visualize focus and context information (like the Table Lense or the Hyperbolic browser) or techniques to visualize collections of documents.

Figure 3 - Examples of multivariate data visualization
(from left to right, Starplots, Biplot and Scaterplots)

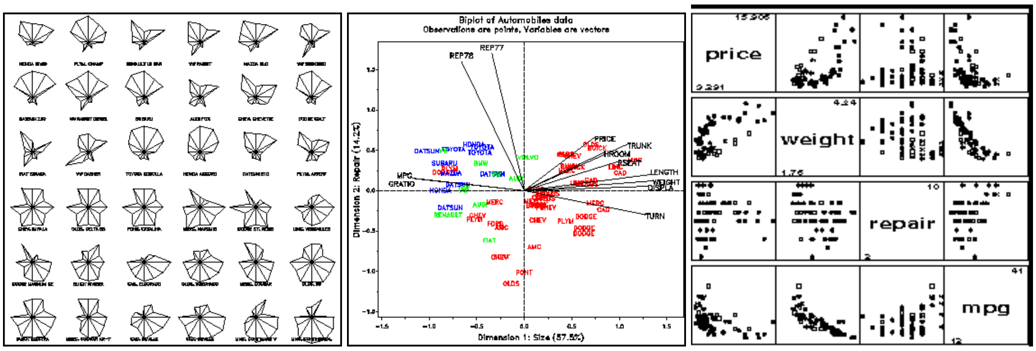
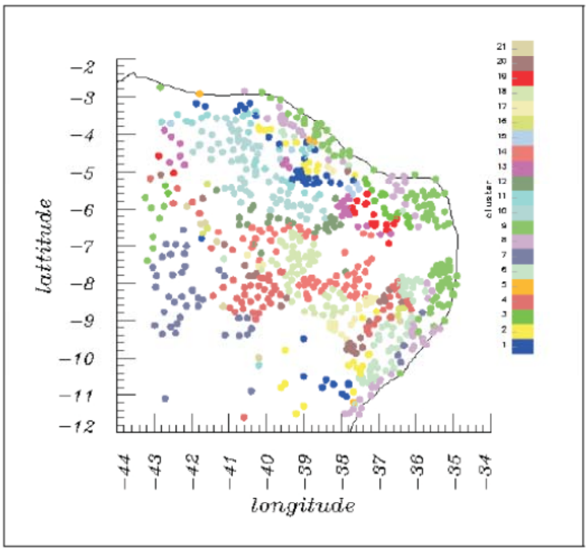
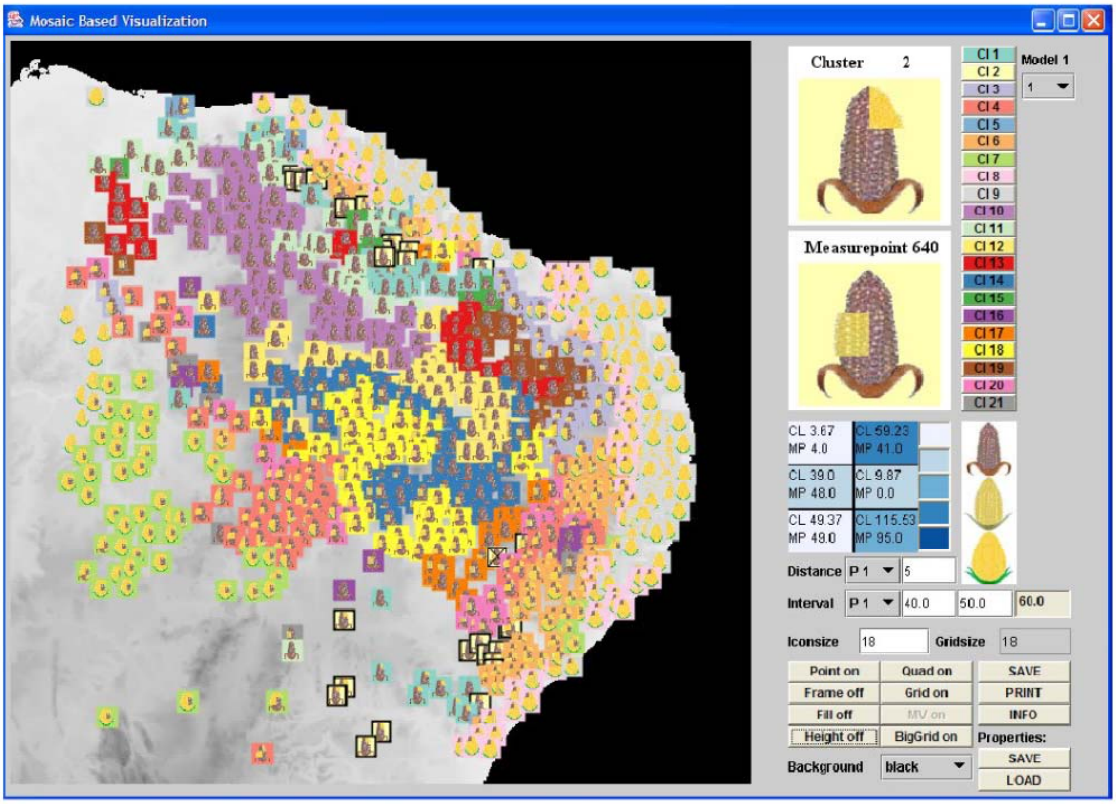


Figure 4 - Visualization of clusters representing the risk of a drought
for maize cultivation during the year 1983 in the semi-arid Northeast of Brazil
based on regional climate model results (Nocke 2005).



The concept-graphing tool available through the HERO Web portal allows scientists to visually encode knowledge structures using conceptual graphing techniques. Users of this tool can produce diagrams to represent the relations between concepts or the process of an experiment or workflow. The example shown in Figure 79 depicts one user's view of the concept of vulnerability to environmental change. Here, vulnerability is a product of three "subconcepts": exposure, sensitivity, and adaptation. Each of these concepts is in turn described by other concepts. All are linked together by using a set of relationships with defined semantics that allows the concept graph to be decomposed into a set of concept definitions stored in description logic (MacEachren 2004).

Figure 5 - Visualizations of the risk of potential total yield loss of maize according to several climate models



The use of these kind of tools allows to visualize where communalities and interlinks between “subconcepts” are. By doing so it helps to identify were more clarification is needed and what common understanding should be reinforced.

Figure 6 - World map of Koeppen Climate Classification

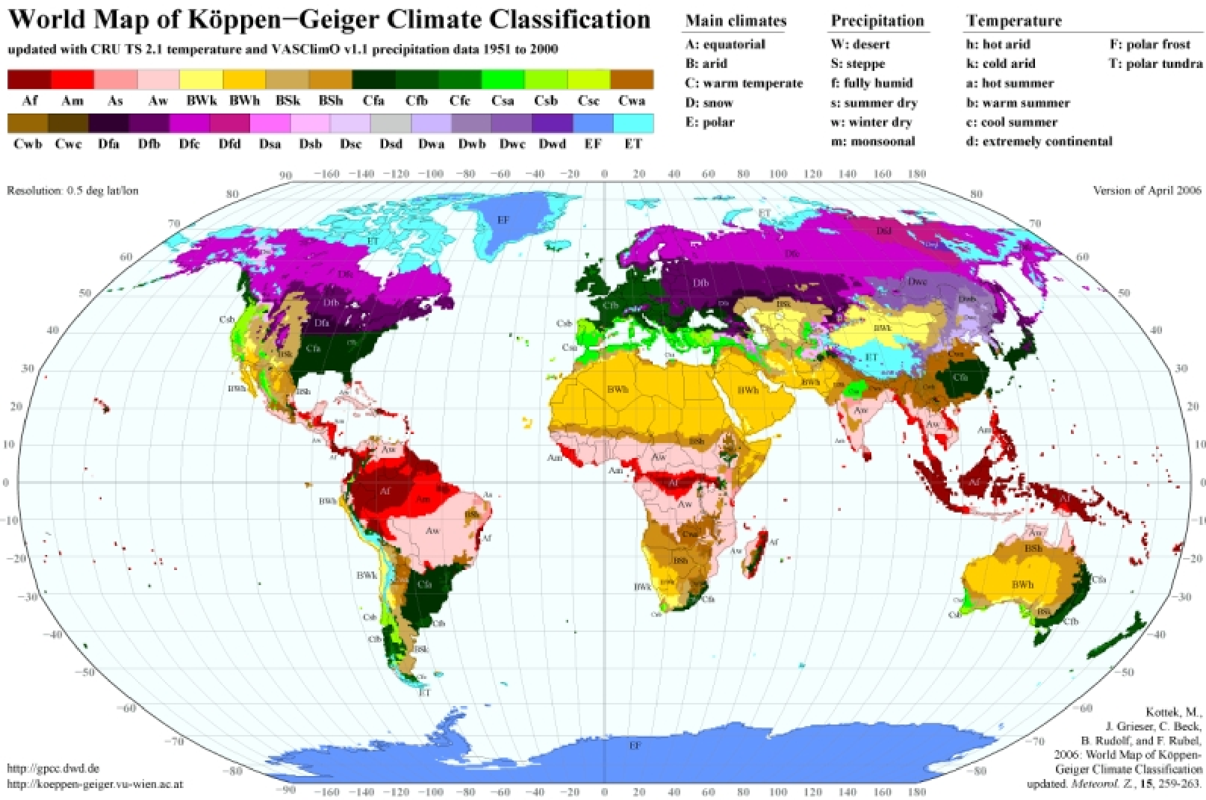
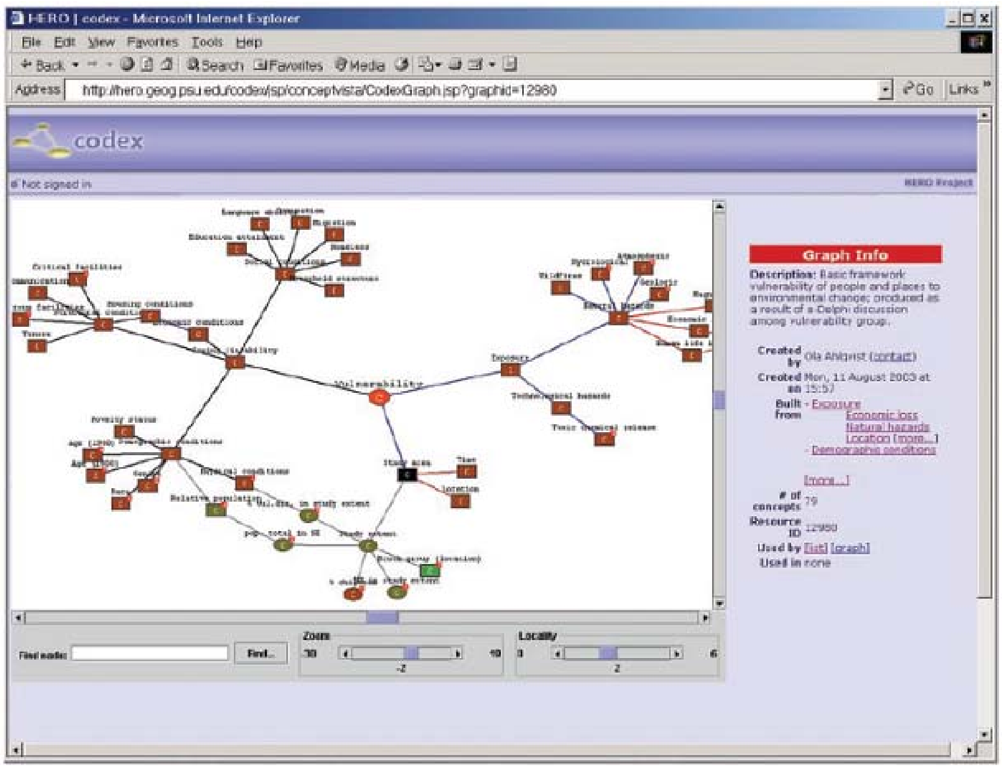


Figure 7 - A concept graph that depicts a HERO researcher's conceptualization of vulnerability. The graph allows concepts, data, and tools to be linked in visual



2.2 3D dynamic modelling of buildings (BRGM)

Evaluation of the seismic vulnerability of structures is performed through an appropriate earthquake damage analysis. Different analysis procedures are used in practice, but their assumptions (analysis method, structural idealization, seismic hazard characterization, damage models) strongly influence the derived fragility curves and have been seen to cause significant discrepancies in the seismic risk assessments made by different groups for the same location, structure type and seismicity.

For instance, current physical vulnerability assessment methods consider a single hazard parameter (e.g. peak ground acceleration, PGA, or macroseismic intensity, etc.), which is generally used to characterize the earthquake loading to be applied to the studied structure. Very recently, some efforts have been made to account for the effect of several ground-motion parameters on the structural damage (Seyedi et al., 2010), by introducing the fragility surface concept in risk assessments for actual structures modelled through nonlinear time-history analysis of multi-degree-of-freedom systems. In this approach, ground-shaking is characterized by two intensity measures, which are selected in order to be poorly correlated. On the contrary, the structural damage is correlated to the selected parameters. To this end, the damage level of a typical reinforced concrete (RC) structure can be evaluated by the use of nonlinear numerical calculations. By considering the parts of the structure that would suffer significant damage during strong ground motions (plastic hinges), an adequate 3D nonlinear robust-yet simplified finite element model is created to allow the numerous computations, with an acceptable cost (see Figure 8). The maximum inter-story drift ratio is used to define the damage level of the studied structure. The relationships between various intensity measures and the computed damage are compared. Such a study can help to find a small number of ground-motion parameters that lead to, when used together to characterize the shaking, the smallest scatter in the estimated damage. Fragility surfaces are then proposed for the studied structure. In this methodology, only the scatter in the estimated damage level due to ground-motion variability is investigated and it is assumed that there is no variation in the material or geometric properties of the structure.

Figure 82: 3-D finite element mesh of an existing 1970s' building