A CONCEPTUAL FRAMEWORK FOR 3D VISUALISATION TO SUPPORT URBAN DISASTER MANAGEMENT

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Abstract
In this paper a conceptual framework is proposed, which aims at establishing link between 3D urban models' characteristics and types of natural disasters. The framework is designed to serve for stakeholders and disaster managers for providing better selection of type of 3D model representations. The paper introduces parameters according to which the types of hazards can be classified. These parameters provide a background to decide on type of model needed. The LoD as defined in CityGML are investigated with respect to needed resolution for a specific data type. The presented framework is tested for visualization of vulnerability due to earthquake risk in Eskisehir, Turkey. The paper concludes with the discussion on advantages and disadvantages of the framework as well as outlining future research.

1. INTRODUCTION

Natural disasters have been causing people's dead and huge economic losses over the history of civilization. As more than half of the world's population currently lives in cities and much of the economic assets concentrate in the cities, natural disaster risks in urban areas are higher due to variety and clustering of elements at risk in urban areas. Today cities are growing and naturally the vulnerabilities increase due to the growing complexity of urban processes. On the other hand human beings have growing impact on the nature (figure 1). This impact has a negative effect on the human society in many cases. Therefore, reduction and mitigation of the vulnerability of citizens requires increased attention and improvement of risk management policies and technology.

A disaster is a function of many factors such as hazards, human vulnerability and insufficient capacity. Risk is defined as the expected losses which could be lives, personal injuries, property damages, and economic disruptions due to particular hazard for a given area and reference period. Hence risk is the product of hazard, vulnerability and coping capacity [22]. Risk assessment is one of the key elements of a disaster management strategy as it allows for better mitigation and preparation. Risk assessment deals with the following questions: Is the computed risk acceptable? Which area(s) are at high risk? Who and what are vulnerable? What are the capacities and recourses? How could the assessed risk be mitigated or reduced? Risk assessment also provide input to decision making, increase risk awareness among decision makers and other stakeholders [19]. Understanding and communicating in a proper way, the assessed risk is a critical element in the preparedness phase [20]. Previous studies have shown that; the presentation of hazard, vulnerability, coping capacity and risk, in the form of digital maps has a higher impact than traditional analogue information representations [14, 9]. Digital maps are progressively used by disaster managers. Many authors believe that further developments towards 3D visualization have the potential for even more effective communication tool ([11], [13], [16], [23]). 3D graphical representation significantly reduces the amount of cognition effort, and improves the efficiency of the decision making process [3], [11], [25]. It is expected that 3D visualisation provided in the proper way, should help the entire disaster management process. However, visualisation has to be done correctly. To achieve such a good 3D visualisation, two aspects have to be observed: appropriate presentation and appropriate tools for interactions.

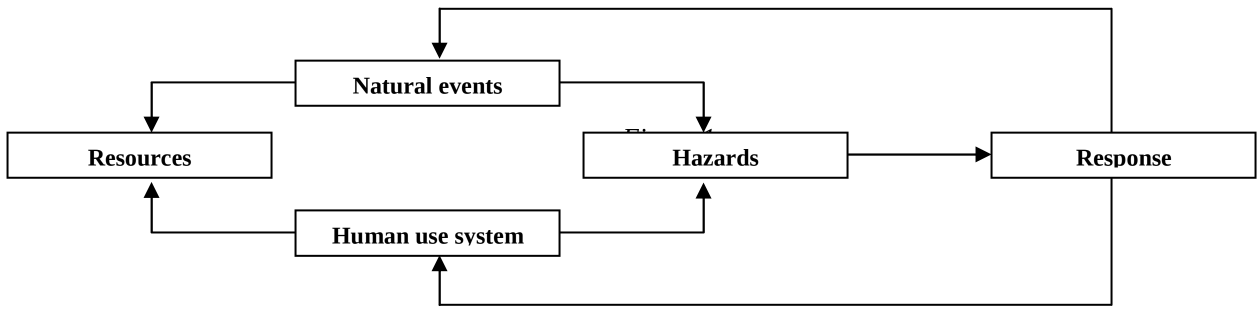

Figure 1 Human and natural system interaction [2]

Use of 3D spatial data for whole phase of disaster management is a new but quite attractive topic in geosciences. There are several studies for use of 3D geographic information in modelling hazard phenomenon and corresponding urban environment. Uitto 1998 proposed a framework, which uses GIS for urban disaster management considering the disaster vulnerability concept. Rajabifard et al and Herold et al [15, 7] outline a framework for establishing an online spatial disaster support system or disaster management and the framework integrate GIS, Spatial Databases and the Internet for Disaster Management concepts. Another study is [24], which discusses an emergency response framework. Technical necessities of multi-risk emergency situation response systems are evaluated from a 3D spatial information perspective in addition to a system architecture is proposed which cover data management and communication subject's of problem areas of these necessities. These studies however are not appropriate for goal of this study, i.e. defining the level of 3D urban modelling in natural disaster risk management.

This paper presents a framework, which establishes a link between the disaster type (such as flood, earthquake) and several components that influence the 3D visualisation. To be able to provide an appropriate 3D visualisation, one should consider various issues, e.g. the resolution of the 3D model, the time/efforts needed to create a model, the availability of software and source data, etc. The goal of the framework is to help the risk managers with preparation of the data for the 3D models they need for a particular disaster type.

Paper consists of five parts. After this introduction part, concepts related to the proposed framework are elaborated. Section 3 presents the framework. Section 4 discusses initial results of visualization for earthquake risk analysis in Eskişehir, Turkey. The paper concludes with a discussion on advantages and disadvantages of the framework as well as outlining future research

2. BACKGROUND

Generally, 3D urban modelling is a holistic process of conceptualization, data capture, sampling and data structuring and depends on the aim of visualization [16]. In risk management, 3D modelling is very much dependent on the type of disasters to be represented and the type of users to be involved in the risk management process. In this section, the related topics are introduced, which are hazard classification, users and 3D urban objects of interest for risk analysis. Since the 3D urban objects can be modelled with different resolution, type of geometry and attributes, aspects of 3D semantic modelling are also briefly introduced.

2.1 Spatial and Temporal Characteristics of Hazard

Several authors have tried to classify the types of hazards and the corresponding risks. For the scope of this paper, we have concentrated on the parameters as introduced by Burton et al 1993. These parameters are 6. **Frequency** reflects the time interval in which a natural disaster occurs. For example: earthquake occurs with a log-normal frequency, while landslide occur seasonally. **Duration** is the period of time that disaster continues. Disaster duration may change from seconds to years. For example earthquakes are very short and landslides are long term processes. **Spatial Dispersion** refers to the pattern of distribution of a hazard over the geographic area in which the hazard can occur. This parameter changes between small to large. **Speed of Onset** is an important variable since it forms warning time. Most extreme ones such as earthquakes, landslides and flash floods give virtually no warning. Other disasters such as drought and desertification act slowly over a period of months or years. **Areal Extent** is the spatial density of related disaster over the whole earth e.g. the earthquake zones are limited. **Temporal Spacing**: Refers to the sequencing and seasonality of disaster events. Some disasters are random like volcanoes while others have seasons such as hurricanes, tropical cyclones, floods. These parameters give sufficient background to find proper 3D spatial object representation needed for our framework. We use the first four parameters and introduce several new as explained below. A combination of ‘frequency’, ‘duration’, ‘spatial dispersion’ and ‘speed of onset’ allows to generate a disaster severity index, which is used to order different disaster types on the hazard type axis of framework. These parameters are also used to define ‘hazard characteristic medium’, ‘data representation’ and ‘indoor and outdoor resolutions’ of model objects (Hazard Characteristic Medium and Element at Risk). Burton’s last two parameters ‘areal extent’ and ‘temporal spacing’ are not applicable for the framework. These two parameters have not direct relation on spatial and temporal specification definition of 3D urban model objects.

2.2 Decision Makers in Risk management (Users)

Different types of 3D urban models and functionality are needed for different user groups. Correct user group determination is important in order to determine the functional content of the 3D urban model. Different users are involved in the different phases of disaster management. For example fire brigade, ambulance and police might be the main responders in emergency phase, while urban planners, and risk management specialist could be the users in the preparation phase. [24], [25] Introducing a fundamental classification of users is outside the scope of this paper. The users considered in this study are general users such as Financial institutions (e.g. World Bank, insurance industry), Academia (e.g. Universities), Private sector (e.g. industrial organizations), Governmental organizations (e.g. governors, municipals), Civil society organizations (e.g. Red Crescent), International financial institutions, Public body itself.

The visualisation and interaction tools are much related to the skills of the users as well. For the scope of this study, we distinguish between technical users and non-technical users. Simple interactions with realistic visualisations fit better the needs of the public and the governmental bureaucrats. Technical persons may need more complex interactions and tools to query information. An elaborated study on visualisation and interaction techniques is given [26]. Here we consider the following interaction levels;

Realistic 3D visualizations (images)

3D walk-through,

Thematic visualization (i.e. façade colours of 3D building blocks to represent a tabular risk index value to)

Spatial and attribute queries,

Complex analysis (such as visibility, buffer and overlay).

2.3 3D Urban Modelling

An important aspect of 3D modelling is the type of objects to be modelled, their representation and the resolution or levels of Detail (LoD). Proposed framework is utilizes previous knowledge on semantic models to define which objects can be used in urban modelling application. Practically the LoD concept can be directly related to the resolution.

2.3.1. 3D urban objects

Various initiatives exist to define objects of interest in urban areas. Among them CityGML is one of the few 3D urban modelling concepts that consider 3D semantic, geometry and topology in a generic sense (i.e. it is not application-oriented). Urban objects of interest in CityGML are subdivided into terrain, vegetation and built form object classes. The most important object s are Building objects: They allow the representation of thematic and spatial aspects of buildings, Another interesting for 3D modelling objects are Relief (i.e. Terrain), Transportation and Landuse classes. Transportation class represents objects of all modes of transportation, for example; a road, a track, a railway, or a square,. LandUse objects describe areas of the earth’s surface dedicated to a specific land use. Several other objects such as City Furniture, Vegetation and Water can be also useful for risk management. CityFurniture objects are immovable objects like lanterns, traffic lights, traffic signs, advertising columns, benches, delimitation stakes, or bus stops. Vegetation: this object class is used to represent solitary three objects, plant cover as surface or plant canopy. The water object represents the thematic aspects and three-dimensional geometry of seas, rivers, canals, lakes, and basins. These object class compose object pool in the framework.

CityGML urban objects can directly be used to identify urban objects of interest also for risk management. All the objects will be considered as an urban model objects pool. A set of objects important for any particular disaster can be subtracted from this pool. The only limitation is the current lack of underground object. However, ongoing research and developments are considering extensions in this direction [27], [28].

2.3.2. Level of Detail:

The abstraction, converted into visible representations is called levels-of-detail (LoD). CityGML provides also a concept of a LOD, which is best developed for buildings, but generally, all the objects can have LoD. For buildings, LoD1 defines a box model and the most detailed LoD4 allows for representation of buildings (Figure 2). Naturally resolution level is increase from LoD0 to LoD4. LoD0 is the 2.5D level, over which an aerial image or a map may be draped. [11], [6] LoD concept is quite generic and suitable for small to large area applications. The concepts of LoD of CityGML are adopted as a starting point for hazard type-resolution relation of proposed framework.

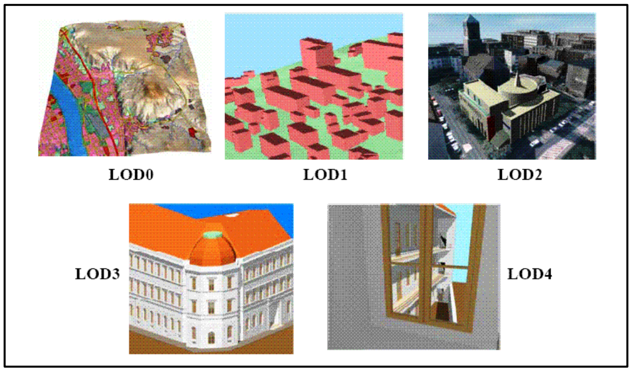

Figure 2. The five levels of detail (LoD) defined by CityGML (source: IKG Uni Bonn)

2.4. Sensor products and 3D reconstruction

After conceptualisation step (agreeing on types of object to be modelled and their resolution), the corresponding 3D models have to be created. Various approaches exist to reconstruct 3D models from different data sources. Data used to generate 3D urban models can be gained from Passive Sensors, Active Sensors or combinations of them [8]. Airborne imaging is a mature technology, today we have huge amount of types of airborne or terrestrial cameras. Each of these camera types provides different resolution, has various coverage, accuracy and precision, and deployment time. Products derived from passive sensors can be either; a) raster-based products; image, stereo image pair, mosaic or panorama, orthophoto, true-orthophoto, b) vector-based 3D products; points, contour, lines [10]. Passive sensor methods are usually cost effective if large scale 3D urban modelling is needed and require combination of aerial and terrestrial images. Aerial images provide reliable footprint and roof height information, while terrestrial images provide façade details. Active sensors emit energy, which is detected by the sensor after reflecting from terrain, buildings, vegetations, etc. objects. Similar to passive sensors, there are two kinds of active sensors: airborne-based and ground-based. The product of airborne-based laser scanners is Digital Surface Model (DSM). DSM gives good overview on large areas. Ground-based systems are ideal for detecting features in vertical direction [5]. However, they may have problems with providing sufficient data for upper portions of tall buildings. Another active sensor type is radio detection and ranging (RADAR). Thanks to its wave length, radar signals penetrate clouds, haze and rain so radar has an imaging capability in all weather condition and day and night. Most urban modelling applications need integration of various data sources, which require hybrid usage of different sensors. This integration can be in the form of simple overlay or multi-data information extraction (increasing the dimensionality by using DSM and 2D images, spatial resolution increasing by using high spatial resolution panchromatic images with multispectral images in relatively low spatial resolution and multi-criteria analysis i.e. to find the most risky area) [10].Depending on the type of product three methods for 3D reconstruction can be distinguished: image-based, point cloud based and hybrid approaches [17].

Sensor products and methods for reconstruction are important factor in our framework. Risk managers have to be aware of how much efforts and money they will need to spend on the obtaining the wished 3D model for visualisation. For example today we have relatively limited number of radar systems (less than 45), compared to more than 130 laser scanners, and thousands of optical systems. This practically means that a method based on products of laser scanning or optical sensors have the chance to be better matched with the resources of a specific municipality. Selection of products is also dependent on the desired LoD, e.g. 3D model textured with images will always require use of optical sensors. The efforts for creating a detailed 3D model (e.g. buildings in LoD3) differ significantly from the efforts needed for obtaining LOD1 model. Our framework aims at helping risk managers in municipalities to take the most appropriate decision on the resolution of the 3D model.

3. THE FRAMEWORK

Proposed framework aims establishing link between 3D urban model characteristics (indoor/outdoor resolution, data representation and data source) and types of natural hazards to guide the design, implementation and integration of the 3D urban models. The framework is designed to generate proper 3D urban models in order to be used as risk communication tool by users. For providing proper 3D Urban Modelling for Disaster Risk Communication our study follows four basic steps. The interconnection of these steps completes the study workflow for certain expected outcomes. These steps are (see also Figure 3);

1. Hazard Assessment,
2. Defining User/Objects Relation
3. Framework
4. Needs Assessment for Visualization

To constructs effective 3D urban disaster risk visualization, the relation between these steps has to be clearly defined. At the first step, 'Hazard Assessment', three characteristics of the required 3D urban model are defined i.e. 'Hazard Characteristic Medium', 'Indoor/Outdoor Resolution' and 'Data Representation'. Desired disaster risk communication tool has two main components, these are urban related model objects (Element at Risk) and 'Hazard Characteristic Medium', the hazard side of the visualization. 'Hazard Characteristic Medium' can be just attribute value of any model object (i.e. vulnerability values of each building object in an earthquake case), or it can be an object (i.e. sea water object in a dynamic tsunami visualization case). 'Indoor/Outdoor Resolution' defines abstraction level of each modelling object. Low spatial resolution involves with low LoD and high spatial resolution involves with high LoD, this definition is valid for indoor and outdoor resolution. 3D data can be represented either by boundary (or surface) or volume approaches (similar to 2D, which is vector and raster). 'Data Representation' defines data and procedures needed for that specific modelling.

The second step is related to defining 'User' and 'Element at Risk'. Each 'User' considers a different 'Element at Risk', which is a urban related component. At the end of these two steps, model objects (consist of two main types, 'Element at Risk' and 'Hazard Characteristic Medium') and their specifications (Indoor/Outdoor Resolution and Data Representation) are ready. Utilization of framework for these model objects with data and required process efforts definitions compose third and forth steps of framework. Subsequent parts of this section follow the statements of these four main research steps.

3.1 Hazard assessment

In the hazard assessment in addition to the Burton's hazard assessment parameters (Frequency, Duration, Spatial Dispersion and Speed of Onset) adapted to the study, three of new parameters are introduced to be able to relate hazard type to urban model. These new parameters are;

> **Intrusion (to the Built Environment)**: Some natural hazards commit their fatal effects on built environment by intrusion of the hazard material into the built structure. This material can be soil as in landslide example or water as in flood and tsunami examples. Intrusion parameter is used to determine the indoor LoD, together with 'Spatial dispersion' parameter. In the CityGML indoor visualization is a piece of the most detailed LoD definition (LoD4). But some hazard visualization cases may need different indoor LoD definitions at low LoD levels (i.e. floor level indoor representation beneficial tsunami case which has relatively large 'Spatial Dispersion', to find effected part of the building object).
>
> **Type of natural hazard**: Hazard classification according to the occurrence place of natural hazard, i.e. beneath the earth's surface (e.g. earthquake), on the earth's surface (topographical phenomena e.g. landslide, avalanches), in the air, i.e. meteorological (e.g. windstorm) and hydrological (e.g. flood). Type of natural hazard is used to 'Hazard Characteristic Medium' definition. For example, Hydrology objects is the most important modelling object for Hydrological hazards and sub-surface modelling may be needed for hazards which occurred beneath the earth's surface.

Physical model: Physical modelling adverts to the design and operation of systems that are based on or derived from physical phenomena (natural hazards in our cases). The modelled phenomena can have different processing characteristics, it can be Mathematical, Data driven (layer based analogue map or GIS) or Combination of first two processing types [21]. These processes can be modelled as static or dynamic. In the Static models, a set of object and relationships between them are described, while in the dynamic models, behaviour of one or more object described over time (i.e. dynamic physical tsunami model, which forecast, the movement of a tsunami wave over time and behaviour when it hits to a rigid object). This parameter is used to define model data representation way. If visualized action is result of a Mathematical model we need complex data representations like voxel-based volume modelling technique. Moreover in that kind of models, behaviour of one or more objects is described over time. On the other hand, static models i.e. data driven, need description of a set of object and relationships between them. In this case, we can use complex representations with simple data representations.

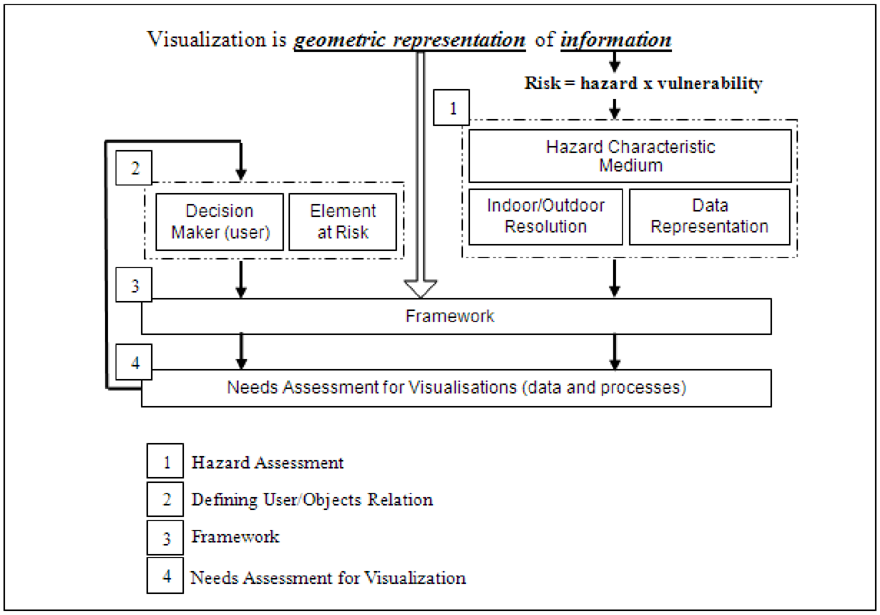

Figure 3.Steps and workflow

The hazard assessment parameters, newly introduced and adapted from Burton's hazard assessment parameters (in section 2.1.), are used to achieve two basic outputs; first to define so called 'severity level' of different hazard types to order different hazard cases on 'hazard type' axis and second to define 'Hazard Characteristic Medium', 'Data Representation', 'Indoor and Outdoor Resolutions' characteristics of urban model.

For first output of this step 'Frequency', 'Duration', 'Spatial Dispersion' and 'Speed of Onset' parameters are utilized to come up a severity index of different hazard types. Main assumption under this idea is that a hazardous event occurred; frequently, for long duration, on a large area and with fast speed of onset, cause most severe damages to an urban environment. Relative comparison of each hazard case can be performed by using these parameters. Each parameter can take 5 different value level and value points of each of these four parameters draw severity function of related hazard type. Area between line and right edge give severity level of hazard type. Figure 4 represent an example application for Earthquake and Landslide hazards. Figure implies that earthquakes are more severe hazard than landslides.

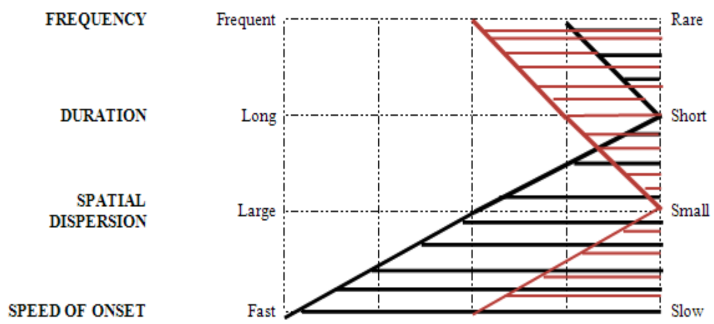

*Figure 4. H*azard severity level of earthquake and landslide cases (black line represent earthquake and red line represents rapid moving landslide)

For the ‘Resolution (LoD)’, ‘Hazard Characteristic Medium’, and ‘Data Representation’ outputs of this step framework use single or combination of hazard assessment parameters. To define ‘Indoor and outdoor resolutions (LOD)’, ‘Spatial dispersion’, and ‘Intrusion’ parameters interpretation utilized in common. ‘Hazard Characteristic Medium’ is described by ‘Type of natural hazard’ parameter and last of all, to identify ‘Data Representation’ combination of ‘Physical model’ and ‘Duration’ parameters are employed.

3.2 Defining User/Elements at Risk

‘Element at risk’ needed to attain an effective risk communication tool, unconceivable without target user group description. In disaster risk management, different ‘Element at Risk’ definitions can be mentioned for each user group. Different users are listed on section 2.2. Target user group can be any of them. This step concerns ‘Element at risk’ definition of 3D urban model as disaster risk communication tool in consideration with ‘User’. These model objects are chosen from urban model objects pool described in the section (2.3.1.).

3.3 Analysis of Data and Process Requirements

Aim of the framework is to find a proper representation for each model object. Each object is pointed out on three dimensional object representation framework. “Level of Detail”, “Level of Data Processing” and the “Hazard type” constitutes the dimensions of this framework. Accumulation of each object points in the framework gave solution area of 3D urban model. To find this area, relation between “Level of Detail”, “Level of Data Processing” and the “Hazard type” (figure 5) is discussed in this framework. The first parameter is the type of hazard. ‘Severity level’ output of hazard assessment is used to order different hazard types. Hazards, which have low severity level value, placed close to the origin and high severity values are placed far from the origin. Resolution output of hazard assessment (Framework section, hazard assessment step) framework relates Hazard Type and Level of Detail axis. Second axis concentrates on the spatial resolution of 3D model objects and their applicability. At this axis LoD as defined in CityGML is investigated and analyzed. In this LoD definition indoor detail can be applicable only at LoD4. But some hazard cases which have ‘intrusion’ may need indoor resolution definitions in the mid parts of this axis. Utilization of this framework tests the completeness of CityGML LoD definitions. Last axis, “Level of Data Processing” is related to the effort to create the needed geometrical representation or availability of the data. Model creation effort is a function of needed cost/effort. For example, some municipalities may need to have a 3D extrusion model of a given area. To create such a model and provide it to the corresponding specialists (e.g. for flood simulation) they will need some basic operations to raw data (if data and software is available). However if they need an indoor model of several buildings, the process needs more effort to create such a product. Processing efforts (represented by the axis LoP) to create the needed 3D representation begins with data collection. Then 2.5 D terrain representation with draped aerial or satellite image can be considered requiring more efforts and therefore comes after the raw data. 3D extrusion – façade texturing with ground images, 3D object generation and integration with the surface, automatic or semi-automatic roof construction, detailed façade modelling by using ground point clouds and last detailed indoor modelling can be at the end of this axis. Processes, which need personal experience, indicate immature functionality and need more effort so they take place at the most right side of LoP axis. Automatic methods to create a product are most left side vice versa. The volume enclosed between LoD – LoP area and the severity value on Hazard Type axis defines the spectrum of the required 3D model. The vertical axis defines the severity level of considered hazard type. This means, if the hazard is more severe, application of risk reduction strategies is more urgently needed than in low severe situations. That kind of implications is important to schedule the risk management strategies and resources.

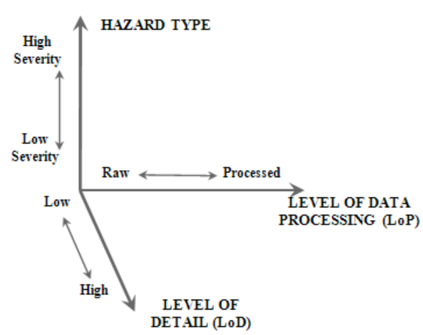

Figure 5. Model Object Representation Framework

3.4 Needs Assessment for Visualization (data and processes)

In this step, available data and products are compared with the results obtained from the framework. Consequently, the framework provides practical outputs to risk and disaster managers. The managers can evaluate whether the models they posses are sufficient for precise analysis of a particular natural hazard or combination of several hazards. The required new data and model can be discussed with respect to the resources of the municipality. For example, according to the framework, a visualisation of a hazard may need a 3D model in LoD4 resolution. However, the municipality may only have high resolution stereo aerial images. To come up to the desired product, they will need additional data like, ground images, building data which contain detailed indoor information, software for image processing of stereo images, 3D geographic modelling software and visualization software to combine detailed 3D geographic objects and other spatial outputs like terrain model. Moreover this modelling process could do with human source for operation of these advanced software. It is up to the decision makers to find the best balance between required model and available recourses.

4. TESTING

As an initial test of the proposed framework, the Eskisehir earthquake case is used. In this case, a visualisation application has to be built for the users in the Eskisehir municipality. The 'user' is municipality staff like urban planners, cartographers and sociologists. They need a clear view of distribution of vulnerability regions over the city. Eskisehir municipality has an urban information system infrastructure so they have related data and software (planning, cartographic and GIS software). In this case, 3D urban model environment is used to visualize previously calculated social, physical and accessibility vulnerability indexes of each building object [29, 30]. Eskisehir is one of the important centres of industry in Turkey. A number of dams and two universities are located within and near the city. Due to its rapid development, Eskisehir has become a popular location for new investments. It is an industrial city in the central Turkey with a population over 500.000. The greatest part of the settlement in the city is located on alluvium. The largest earthquake (Ms: 6.4) was occurred in 1956. Pilot area is a part of city centre and some sort of different city development texture like low rise, historic buildings and high rise apartments. There are nearly four hundred buildings in the case area.

Step1. Hazard Assessment:

The vertical axes 'Severity level' is generated in case of multiple hazard types. In this case only one hazard is considered and therefore a (horizontal) cross section of diagram on Figure 5 is used. 'Resolution' (LoD), 'Hazard Characteristic Medium' and 'Data representation' definitions are defined as follows: Earthquake effects large area, and these is no intrusion so extruded block buildings, at LOD1 of CityGML, is suitable at this case. Moreover, earthquake is a disaster which occurred beneath the earth's surface but aim of the model is visualization of vulnerability index values of each building. Therefore Hazard Characteristic Medium is a tabular index value of each building at this case. Because of its data driven structure, used data representation is B-rep.

Step2. Defining User/Objects Relation:

Technical municipality staffs, non-GIS experts, constitute the user group of generated model. First three interaction levels (section 2.2.) make up the functional capabilities of desired urban model. They need relatively realistic urban environment. To construct this realistic urban environment and express the aim of the visualization Element at Risk is defined as; Building objects, Relief, City Furniture (utility pole, street lamp), Transportation and Vegetation in this case.

Step3. Framework:

Model object defined at the previous step are represented on LoD1 of CityGML with some modifications. For example in the CityGML LoD1 building object definition, there is no façade image mapping but the 'user' request is in that way and the model is generated buildings in LoD1 with low resolution façade images. Model objects and their representation ways in the case can be listed as; Building objects; simple blocks, with low resolution façade texturing, Relief object; 2.5 D TIN based, generated from contour maps, City Furniture (utility pole, street lamp) objects; point objects locations represented with related symbols to improve reality, Transportation object; road surfaces draped on the terrain object, Vegetation object; point objects locations represented with related symbols to improve reality.

Figure 6 represents application of framework for this case. Normal letters denote object representations found by framework and italic letters represent data sources needed to attain these representations. Lines these letters symbolize the needed processing effort.

Step4. Needs Assessment for Visualization (data and processes):

Utilized data sets and their availability at the beginning of the application can be seen in table 1. Available data for urban modelling; Vector layers from Eskisehir Municipality Digital City Information System, Street and Building foot print layers, 1/25000 digital contour maps. To construct building objects, façade images and building height data thereto the present data is needed and collected after study began by field survey.

Process steps to come up urban model framework shown; 2.5D DEM generation from digital contour maps, generation of LoD1 façade textured B-rep buildings by using building height information and ground images, draping; city furniture, tree points, road data and building models with terrain model, relating tabular index data (Hazard Characteristic Medium in this case) to the building objects (figure 7).

Table 1. The model objects and required data sources (municipality's √existing data, × (non-exist at the beginning of the modelling) lack of these data was found by utilization of framework and acquired during the modelling of the case study.)

Object / Source	Building	Furniture	Transportation	Vegetation	Relief
Contour Map					√
Digital Vector Layer	√	√	√	√	
Façade Image	×				
Building Height	×				

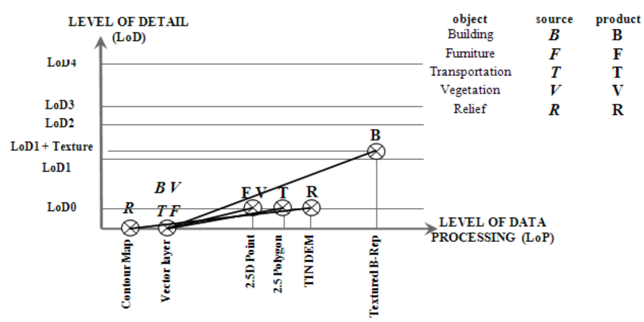

Figure 6.Cross section of framework for earthquake case

Figure 7. General View from the 3D city model generated for earthquake case

5. 5. CONCLUSIONS

The proposed framework establishes a link between the disaster type and various hazard assessment parameters (Frequency, Duration, Spatial Dispersion, Speed of Onset, Intrusion, Type of Natural Hazard, and Physical Model) which determine the needed 3D model for appropriate 3D visualisation of risk vulnerability. When discussing 3D visualisation, many issues have to be considered, e.g. the resolution of the 3D model, the time/efforts needed to create a model, the availability of software and source data, etc. In the presented framework these are derived on the basis of the hazard assessment parameters.

The proposed framework can be used as a tool by the risk managers to decide on the necessary data types for 3D models to be used in a particular risk assessment (for simulation and visualisation). The proposed framework reveals in a better way the relation between hazard types and the corresponding 3D visualization, which consequently helps in the preparation for a disaster and the strategy development needed for risk management. The main expected benefit of this proposed framework is the ability to create understandable, yet well-balanced 3D models to be used as a risk communication tool. Our study has shown that technological developments in the CityGML, 3D data sources, data processing and 3D visualization could be easily adapted to the framework. The first tests are very promising and well-accepted by the risk managers.

However, the initial tests have revealed that all the three axes require refinements and further development. LOD's as currently defined by CityGML may not be sufficient for all the types of disasters. For example, in some cases (e.g. flood) an indication about the floors is needed, without need to create LOD4. Combinations of CityGML LOD's may be more appropriate to be established. For example, low outdoor (LoD1) resolution with low indoor resolution (floor level) to be used for a hazard application, which has a large spatial dispersion and an intrusion to the built environment (e.g. tsunami). Future work will investigate these possibilities in detail.

The other two axes in the framework Hazard type and Level of Data Processing demand further elaborations as well. The parameters for defining the severity of a hazard will be further refined and tested for more disasters. Currently the level of data processing is established by a rough estimation of the needed resources to obtain a specific model. Further investigations are needed to define appropriate parameters, which influence the data processing.

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