A CONCEPTUAL FRAMEWORK FOR 3D URBAN DISASTER RISK VISUALIZATION IN GEO-SPATIAL ENVIRONMENT

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

SERKAN KEMEÇ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
GEODETIC AND GEOGRAPHIC INFORMATION TECHNOLOGIES

SEPTEMBER 2011

Approval of the thesis:

A CONCEPTUAL FRAMEWORK FOR 3D URBAN DISASTER RISK VISUALIZATION IN GEO-SPATIAL ENVIRONMENT

submitted by **SERKAN KEMEÇ** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Geodetic and Geographic Information Technologies Department , Middle East Technical University** by,

Prof. Dr. Canan Özgen ________________
Dean, Graduate School of **Natural and Applied Science**s

Assoc. Prof. Dr. Ayşegül Aksoy ________________
Head of Department, **Geodetic and Geographic Inf. Tech.**

Prof. Dr. H. Şebnem Düzgün ________________
Supervisor, **Mining Engineering Dept., METU**

Examining Committee Members:

Prof. Dr. Oğuz Işık ________________
City and Regional Planning Dept., METU

Prof. Dr. H. Şebnem Düzgün ________________
Mining Engineering Dept., METU

Prof. Dr. Ahmet Cevdet Yalçıner ________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Veysi İşler ________________
Computer Engineering Dept., METU

Assoc. Prof. Dr. Çiğdem Varol ________________
City and Regional Planning Dept., Gazi Univ.

Date: 16.09.2011

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name : Serkan KEMEÇ

Signature :

ABSTRACT

A CONCEPTUAL FRAMEWORK FOR 3D URBAN DISASTER RISK VISUALIZATION IN GEO-SPATIAL ENVIRONMENT

Kemeç, Serkan
Ph.D., Department of Geodetic and Geographic Information Technologies
Supervisor: Prof. Dr. H. Şebnem Düzgün

September 2011, 203 pages

Visualization could be defined as the graphical presentation of information, in which the main aim is to improve the user's perception. In all phases of the disaster management, decision makers come across huge data sets with spatio-temporal content. It is hard to deal with these sets in order to find answers to the main question of "How can we decrease the losses due to disasters?", which is at the core of the disaster management concept. To furnish this aim, disaster risk information has to be transparent and clearly stated to the public, decision makers and disaster managers. This might be more sophisticated than the calculation of the risk.

Taking precautions before a disaster to reduce the causalities and lossess engendered by natural disasters is relatively cheaper, and more importantly, better than cure. To achieve enhanced preparations for all kinds of disasters, visualization is quite an important tool for decision support and risk communication. The basic aim of this research is to propose a conceptual framework, with the consideration of all stakeholders related to the disaster management issue to have a better risk communication, and to guide the design, implementation and integration of the 3D urban modeling tools into disaster risk visualization. Moreover, an empirical methodology is also developed for the generation of visualization solutions through the design, and employment of the tool for disaster management framework. The proposed framework has three main phases .These are the definition of visualization components, object representation, and needs assessment. A new LoD hierarchy with indoor is proposed to visualize all the possible 3D urban disaster situations in the first phase. Then, a decision rule with eight attributes is proposed in the second phase to establish a link between the hazard type and the LoD needed in a 3D urban model for visualization. This decision rule is applied in a proposed three-level hierarchycal structure. The assessed objects of these three levels are urban, sub-urban zone and building. Moreover, a method to define the needed sub-urban zone is proposed. Finally, different 3D urban modelling methods are analyzed to define the data and process needs of possible 3D urban disaster visualization situations.

Two natural hazard cases are studied within the scope of this dissertation to assess the operability of the proposed framework. These implementations involve one earthquake and one tsunami case. Special attention is paid to finding one specific sample for two modelling viewpoints, namely static and dynamic. The first applications of the proposed framework with all the related features prove quite promising.

Keywords: GIS, information visualization, disaster management, 3D urban environment modeling

ÖZ

COĞRAFİ MEKANSAL ORTAMDA 3B KENTSEL AFET RİSK GÖRSELLEMESİ İÇİN BİR KAVRAMSAL ÇERÇEVE

Kemeç, Serkan
Doktora, Jeodezi ve Coğrafi Bilgi Teknolojileri Bölümü
Tez Yöneticisi: Prof. Dr. H. Şebnem Düzgün

Eylül 2011, 203 sayfa

Görselleme temel amacı kullanıcının algı seviyesini artırmak olan, bilginin grafik sunumu olarak tanımlanabilir. Karar vericiler afet yönetiminin bütün aşamalarında mekansal-zamansal içeriğe sahip büyük veri setleriyle karşı karşıyadırlar. Afet yönetimi kavramının merkezinde olan "Afet kaynaklı kayıpları nasıl azaltabiliriz?" sorusuna yanıt bulmak amacıyla bu setlerle ilgilenmek zordur. Bu amacı gerçekleştirmek için afet riski bilgisinin şeffaf olması ve kamuya, karar vericilere ve afet yöneticilerine açıkça ifade edilmesi gereklidir. Bu riskin hesaplanmasından daha karmaşık olabilir.

Doğal afetlerin ortaya çıkardığı kayıpları ve zararları azaltmak için afetten önce önlem alınması görece düşük maliyetli ve daha da önemlisi iyileştirmeden daha iyidir. Görselleme bütün afet türlerine karşı gelişmiş hazırlığa sahip olmak amacıyla önemli bir karar destek ve risk iletişimi aracıdır. Araştırmanın temel amacı, doğal afet yönetimiyle ilgili tüm paydaşları göz önünde bulundurarak daha gelişmiş risk iletişimi sağlamayı ve 3B kent modelleme araçlarının tasarımı, uygulaması ve doğal afet risk görsellemesiyle bütünleştirilmesine yol göstermeyi amaçlayan bir yapısal çerçeve önerisi geliştirmektir. Ayrıca, görselleme çözümlerinin geliştirilmesi için, söz konusu aracın doğal afet yönetim çerçevesi yönünde tasarımı ve uygulaması yoluyla bir deneysel yöntem de geliştirilmektedir. Önerilen çerçevenin üç ana aşaması bulunmaktadır. Bunlar görselleme bileşenlerinin tanımlanması, nesne temsili ve ihtiyaç analizidir. İlk aşamada bütün olası 3B şehir afet durumlarını görselleştirmek amacıyla iç mekânı göz önüne alan yeni bir detay seviyesi (DT) hiyerarşisi önerilmektedir. Bunun ardından ikinci aşamada, tehlike türü ve görselleme için bir 3B şehir modelinde gereksinim duyulan DT arasında bir bağlantı kurmak için sekiz özniteliği olan bir karar kuralı önerilmektedir. Önerilen bu karar kuralı üç aşamalı hiyerarşik bir yapıda uygulanır. Bu üç aşamada değerlendirilen nesneler şehir, şehir altı bölge ve binadır. Dahası şehir altı bölgeyi belirlemek için de bir yöntem önerilmiştir. Son olarak, olası 3B şehir afet görselleme durumlarına dair veri ve süreç gereksinimlerini tanımlamak için farklı 3B şehir modelleme yöntemleri analiz edilir.

Bu tez kapsamında, önerilen çerçevenin işletilebilirliğini değerlendirmek için iki doğal afet tehlikesi durumu incelenmiştir. Bu uygulamalar bir deprem ve bir tsunami vakasını kapsar. Statik ve dinamik olmak üzere iki modelleme görüşü için birer örnek seçilmesine özel bir önem verilmiştir. Önerilen çerçevenin ilgili bütün özellikleriyle beraber ilk uygulamalarının umut vaat edici olduğu görülmüştür.

Anahtar Kelimeler: CBS, bilgi görselleme, afet yönetimi, 3B kent ortamları modelleme

To My Family…

ACKNOWLEDGMENTS

I would like to express my sincerest thanks and deepest respect to my supervisor Prof. Dr. H. Şebnem Düzgün for her guidance, continuous support and encouragement throughout this study. She has always been very patient to me during the course of this study. I feel very lucky to have worked with her and to be acquainted with her wisdom. She has always been more than a supervisor to me.

I would like to express my special thanks to my committee member Prof. Dr. Oğuz Işık for his contributions and continuous support throughout this study. I would also like to thank my committee member Assoc. Prof. Dr. Veysi İşler for his valuable suggestions. The other committee members, Prof. Dr. Ahmet Cevdet Yalçıner and Assoc. Prof. Dr. Çiğdem Varol are also gratefully acknowledged.

This study was supported by the State Planning Organization (DPT) Grant No: BAP-09-11-DPT-2002K125/510 under the OYP programme. Moreover, GGIT and MODSIMMER provided a marvelous research and work environment.

My sincere thanks go to all my professors and instructors in the department of GGIT. I would like to thank all my friends and colleagues in GGIT for their friendship and support, particularly Kıvanç Ertugay, Ali Özgün Ok, Aslı Özdarıcı, Dilek Koç San, Arzu Erener, Pınar Aslantas Bostan, Reşat Geçen, Deniz Gerçek, Gülcan Sarp, and Ayten Koç. With them, the department became a more livable place.

I would like to thank Assoc. Prof. Dr. Sisi Zlatanova for her comments and advices about my studies during the six months I spent in Section GIS Technology, Research Institute for the Built Environment (OTB), Delft University of Technology, Delft, the Netherlands. I am also grateful to all the friends I met in Delft. Their friendship made the stay in Delft a pleasant experience.

I would like to show my deep gratitude to my father İbrahim, my mother Bahriye, my brother Berkan and my sister Berna for their patience and continuous support, which contributed to the fulfillment of this work. I would also like to express my sincere thanks to my wife's family, indistinguishable from my own mother, father and sister, Hatice, Celalettin and Bahar.

Last but not least, I wish to express my heartfelt thanks to my family and my wonderfully supportive wife Seher for their endless love, motivation, understanding, and encouragement throughout my study. I always felt her support beside me in each step of my thesis from the beginning till the end. Her support and sensibility gave me extra strength to overcome the difficulties I faced throughout my study. Besides, my little daughter Doğa came into the world in the middle of the study as the sun to our lives.

ABREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AEC	Architecture Engineering Construction
AHP	Analytic Hierarchy Process
ASCII	American Standard Code for Information Interchange
AR	Augmented Reality
BIM	Building Information Modeling
B-reps	Boundary Representations
CAD	Computer Aided Design
CBD	Central Business District
CCD	Charge-coupled device
CSG	Constructive Solid Geometry
CityGML	City Geography Markup Language
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EDISON	Edge Detection and Image Segmentation System
FM	Facility Management
GCP	Ground Control Point
GEBCO	General Bathymetric Chart of the Oceans
GIS	Geographic Information System
GIScience	Geographic Information Science
GML	Geography Markup Language
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
HT	Hazard Type
IDW	Inverse Distance Weighting
IFC	The Industry Foundation Classes

ISO	International Organization for Standardization
LIDAR	Light Detection and Ranging
LoD	Level of Detail
LoP	Level of Processing
MADA	Multi-Attribute Decision Analysis
OGC	Open Geospatial Consortium
RMSE	Root Mean Square Error
RS	Remote Sensing
SDI	Spatial Data Infrastructures
SDSS	Spatial Decision Support System
SOM	Self Organizing Map
SSA	Small Statistical Area
TGIS	Temporal Geographic Information System
UML	Unified Modeling Language
XML	Extensible Markup Language
VR	Virtual Reality
VRML	Virtual Reality Modeling Language

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

1.1 Motivation

Since the 1980's, visualization has come to be a major research challenge area of the Geographic Information Sciences (GISciences). Initially the adaptation of the great potential of the digital systems to the traditional cartography constituted the main research focus; however, as time progressed, the cognition came into the focus of the visualization studies (Goodchild, 2008). Today, there is no doubt about the importance of the visualization on the human cognition. On the other hand, contextual research and methodologies are needed to connect data derivation and structural developments with the wide range of real word applications. Natural hazards constitute one of the most critical ones.

Visualization could be described as the process of rendering any kind of phenomena visible (Oxford English Dictionary). To make the phenomena visible, certain types of visualization tools are used. These tools include charts, maps or truly 3D representations.As a visualization tool, 3D geometrical representation of the spatial information constitutes the contextual scope in the dissertation.

The words visualisation and visualization (with "z") have different meanings and the one that is referred to in the title of the dissertation and throughout the study is the latter. The term visualisation is defined in the Oxford English Dictionary as;

"The power or process of forming a mental picture or vision of something not actually present to the sight"

On the other hand, the term visualization has two extra internal meanings above this definition. First, the concept of visualization has tight relations with computer technology to explore data. Second, visualization focuses on the deeper understanding of the acquisition of data (Visvalingam, 1994).

In the visualization literature, there are two main approaches of the classification of visualization. One of these classification methodologies approaches the concept from the usage side, and the other approach uses the visualized phenomena to classify the visualization methods.

Ganter (1988) used the purpose of visualization in order to classify the visualization approaches. According to this approach, visualizations can be classified within four classes. These classes are;

- Exploratory visualizations
- Design visualizations
- Reference visualizations
- Presentation visualizations

In the first type of visualization, the gathered information of a model is represented in a simplified form to convince the user. The most common example of the the second visualization class, which is design visualizations, is CAD drawings. In these visualizations, preliminary results are transposed to the user by these types of visualizations. The third and the fourth visualization approaches have common features. In both of these visualization cases, visualization graphics are formed with the principles or procedures, so these are slightly out of the visualization designer's control.

Turk (1992) used the phenomena to be visualized to classify the visualization approaches. In this taxonomy, the visualization approaches are categorized into nine different classes:

- Phenomena visualization
- Meta-phenomena visualization
- Phenomena change visualization
- Visualization of the relations between phenomena
- Casual visualization
- Meta-casual visualization
- Information system (GIS) structure visualization
- Analysis process visualization
- Motivational visualization

In the visualizations of the phenomena, a real world phenomenon is depicted. The visualized phenomena can be related with a local point or can have a regional coverage, e.g. air pollution visualization for a specific place. In the second class of Turk's classification, visualizations are formed on meta-phenomena such as content, quality or accuracy, etc. In the third class, the changes in a phenomenon are illustrated over a specific period. The relationships of the spatially related phenomena constitute the content of the fourth class visualizations. In the casusal visualizations, representation of cause-effect relationships is performed between the phenomena of interest, such as wind and air pollution dispersal. The casual relationships dealt with, for example reliability, validity, etc., are visualized in the sixth visualization class. An example to this can be the visualization of the probability of air pollution spreading for the given wind direction. In the information system visualizations, the analysis and display functionality of the information system are used to create depictions from different databases. The graphic representation of the analyzed processes is used to generate visualizations in the class of the analysis process visualization. In the last class of the Turk's visualization classification, graphic displays, created to catch the viewer's attention, can be found (Turk, 1992).

The visualization cases that were focused on in this dissertation could be categorized as information system (GIS) structure visualization in accordance with Turk's classification of visualization. Moreover, according to the purpose of the visualizations, which is the approach of Ganter, the visualization cases that are focused on could be considered as examples of presentation visualization.

The visualization of the spatial data is the most basic task in the field of GIS. Thanks to data visualization, human eye can recognize the patterns and relationships, which are inherently stored in the data. Spatial information is the most important tool for the human cognition to recognise the real word processes (figure 1.1). Therefore, with communication capability of the visualization, a spatial phenomenon is more efficient and easy to understand.

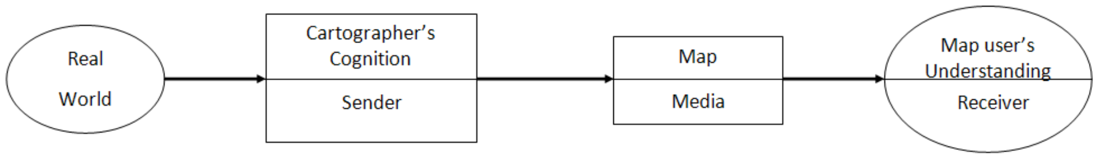


Figure 1.1. The transmission model of cartographic information (Lin and Zhu, 2005)

The proposed framework in this thesis is constructed based on visualization with 3D in GIS environment. 3D visualization might have the advantages of sophisticated visualization techniques in addition to the naturally inherited visualization advantages. There are numerous reasons to choose 3D visualization as a communication tool. These reasons could be summarized as follows:

- Thanks to the gaming industry, computer graphics hardware is now faster than before and while it evolves with an increasing acceleration day by day, it has become cheaper than ever. Unlike the gaming industry, natural hazard applications generally affect large areas, so they need large-scale approaches. In addition to the graphic hardware, 3D graphic industry finds solutions for the large-scale data representation issues. These improvements lead to the achievement of appropriate and effective visualization results.

- Apart from the developments for static 3D representations, dynamic visualization technology is also getting strength. High-quality real time rendering methods support this strength. Robust dynamic visualization capabilities in 3D are also very useful for time-dependent dynamic data. Visualization of temporal processes like natural hazards could benefit directly from these developments (Wood et al. 2005).

Today Geographic Information Systems (GIS) has substituted the conventional manual systems for map generation as a visualization tool. All kinds of geographical scientific visualizations could be possible by using GIS for each scale and application, which has a spatial component. Although the representation of the objects in the form of truly 3D is still at the developmental stage, different representation ways of the spatial data is crucial for today's GIS technology. This multi-representational characteristic of the GIS provides improved interaction level if it is compared with the traditional mapping methods. The design of the visualization is a critical process especially when these visualizations are employed for a spatial decision support system (SDSS) (Wood and Brodlie, 1994). The components of the GIScience, GIS, RS, and GPS, which are increasingly utilized by the aforementioned SDSSs, are strong tools for entire disaster management circle and commonly recognized as key support tools (Thomas et al., 2006).

3D visualization has a big potential for being an effective tool for visual risk communication at each phase of the decision-making process in disaster management (Marincioni, 2007). 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 (Martin and Higgs, 1997). Graphical representation significantly reduces the amount of cognition effort, and improves the efficiency of the decision making process (Christie, 1994), therefore disaster managers increasingly use digital maps. Better disaster management strategies can be designed by visualization. The advances in GIS and RS supported visualization have a potential to improve the efficiency of disaster management operations by being used as a risk communication tool.

Natural disasters have been responsible for the deaths of millions of people and huge economic losses over the history of civilization. As more than half of the world population currently lives in cities and most of the economic assets are concentrated in the cities, natural disaster risks in urban areas are higher due to the 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. Hence, the reduction and mitigation of the natural disaster risk require the development of effective disaster management policies.

A disaster is a function of risk processes. It results from a combination of hazards, human vulnerability and insufficient capacity. Risk is defined as the expected losses, which may involve lives, personal injuries, property losses, and economic disruptions due to particular hazards for a given area and reference period. For this reason, risk is the product of hazard, vulnerability and elements at this risk (WMO, 2002).

Disaster management is a cyclic process (figure 1.2). The phases of the cycle are response, recovery, mitigation and preparedness, and the temporal extent of each phase is not definite for each disaster situation. Although there are no definite borders among those disaster phases illustrated in figure 1.2, using this cycle is efficient to develop the disaster management strategies.

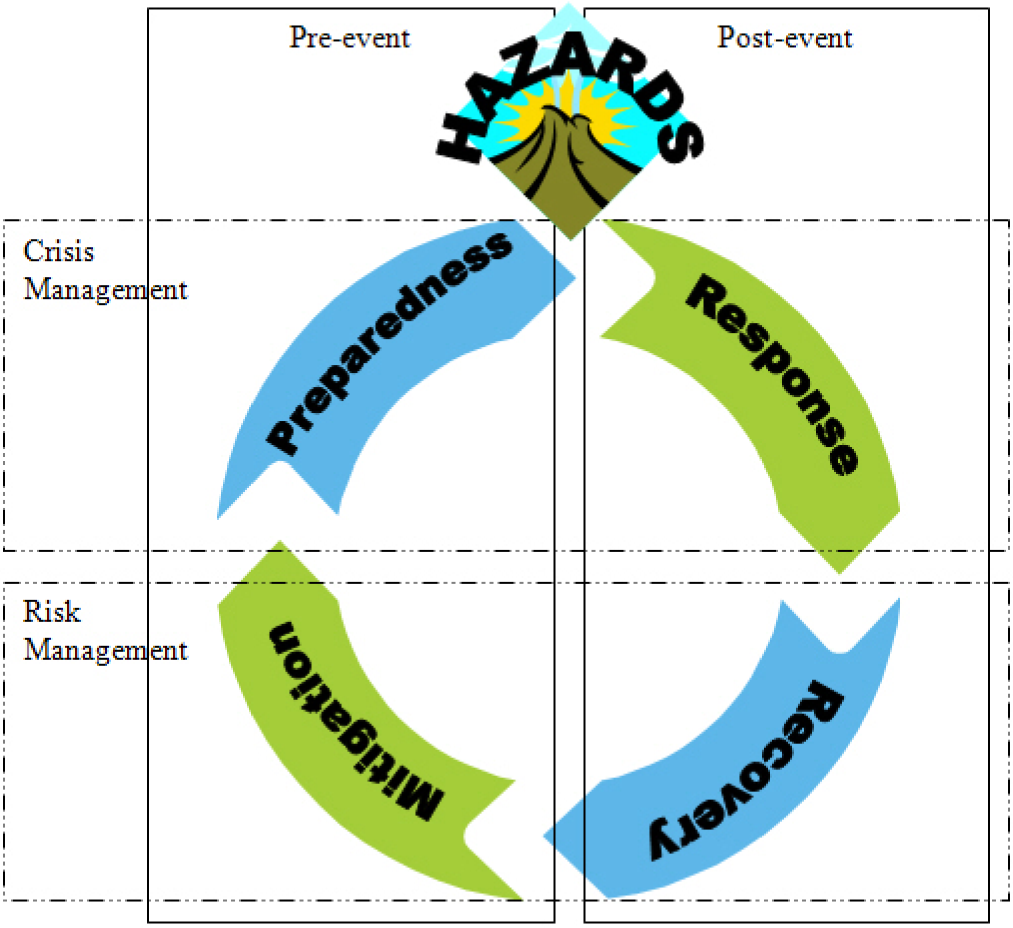


Figure 1.2. Disaster management cycle

Risk assessment is one of the key elements of a disaster management strategy and provides information that is useful for all stages of the disaster management cycle. Risk assessment gives answers to the following questions: Is the computed risk acceptable? Which area(s) is/are at high risk?, Who and what is vulnerable?, What are the capacities and recourses? How could the assessed risk be mitigated or reduced? Risk assessment also provides input to decision making and increases risk awareness among decision makers and other stakeholders.

In order to mitigate the risk and prepare the expected results of the disaster situation, preparedness constitutes one of the most important pre-disaster phases of the disaster management framework. Taking precautions before a disaster helps to reduce the losses due to natural disasters. The key elements of each disaster management phase are listed in table 1.1. As can be seen in the table 1.1, risk communication is one of the key elements of preparedness phase of disaster management.

Table 1.1. Key elements of disaster management (source: IDB, 2000)

PRE-DISASTER PHASES				POST-DISASTER PHASES	
Risk identification	Mitigation	Risk Transfer	Preparedness	Response	Recovery
Hazard assessment	Physical structural mitigation works	Insurance/ reinsurance of public infrastructure and private assets	Early warning systems Communication systems	Humanitarian assistance/ rescue	Rehabilitation / reconstruction of damaged critical infrastructure
Vulnerability assessment	Land-use planning and building codes	Financial market instruments	Monitoring and forecasting	Clean-up, temporary repairs and restoration of services	Macroeconomic and budget management
Risk assessment	Economic incentives	Privatization of public services with safety regulations	Shelter facilities Emergency planning	Damage assessment	Revitalization of affected sectors
GIS mapping and scenario building	Education, training and awareness	Calamity funds (national and local level)	Contingency planning (utility companies / public services)	Mobilization of recovery resources	Incorporation of disaster mitigation components in reconstruction

The main aim of the risk communication is to avoid any hazardous event causing any kinds of harm to humanity. Life bears an inherent uncertainty and this makes risk an inevitable factor in nearly every decision taken. Therefore, by recognizing the uncertainty of hazardous situations, stakeholders of all natural disasters could act more accurately with accurate decisions.

Stakeholders can be defined as any person or group of persons whose lives could be impacted by a given risk. Early views on risk communication paid little attention to stakeholder concerns or opinions. Because of this limited view, the early line of vision for risk communication is in a linear manner. It could be defined as one-way dissemination of information.

The US National Research Council (NRC) (1989) completed a research about risk communication. According to the result report, risk communication is a key component in the risk assessment, in this wise, in the disaster management. The same institution provides a definition for risk communication in the book "Improving Risk Communication";

> *"Risk communication is an interactive process of exchange of information and opinion among individuals, groups, and institutions. It involves multiple messages, not strictly about risk, that express concerns, opinions, or reaction to risk messages or to legal or institutional arrangements for risk management."*

The data necessary for the risk assessment and disaster management generally have a spatial component, and change over time. Therefore, the use of GIS has become essential in urban disaster management. In disaster management, scientific information presentation is more useful for decision makers; if the presentations are pertinent and visually understandable, then it is relevant that risk communication is achieved more prosperously.

Risk mapping in urban context is complicated since the number of elements at risk in an urban environment is varying and complex (e.g. social, economical, cultural, historical, and physical elements at risk). By definition, visualization is the issue of graphical presentation of information; hence, 3D visualization through Geographical Information Systems (GIS) and Remote Sensing (RS) has the potential for providing a better risk communication tool for the representation of natural disaster risk in urban areas.

Many authors believe that further developments towards 3D visualization have the potential for even more effective communication tools (Raper, 1989; Zlatanova et al. 2002; Kolbe et al., 2005; Marincioni, 2007). 3D graphical representation significantly reduces the amount of cognition effort, and improves the efficiency of the decision making process (Kolbe et al., 2005; Zlatanova, 2008). However, visualization has to be done correctly. It is easy to create ineffective and misleading visualizations.

Visualization should not be generated merely based on traditional methods but rather it should provide the users necessities. Thus, a wise methodology is required to choose the appropriate GIS visualizations (Turk, 1992).

1.2 Purpose and Scope

The basic aim of this dissertation is to propose a conceptual framework for several stakeholders of the disaster management so that this framework can be used as risk communication between them to guide the design, implementation and integration of the 3D urban models in disaster management. Moreover, the proposed framework is implemented based on case studies selected from different natural disaster types (earthquake and tsunami). During these implementations, the applied 3D visualization methodologies were evaluated through surveys among the stakeholders of disaster managers and the methodologies are revised according to the needs and expectations of the stakeholders.

The conceptual framework, developed in this research fulfils the following aims:

- To constitute a basis for the 3D urban disaster management related visualization tools

- To improve the efficiency of disaster management operations by using geographic visualization tools as a risk communication instrument

Based on the above stated aim, the following research questions are answered:

1. What are the parameters to be considered to construct an effective 3D urban disaster risk visualization?

2. How the links between the parameters in the first question can be systematically modelled?

3. How they can be incorporated to 3D urban disaster risk visualization?

4. For several cities under the influence of various disasters, which level of details of urban model objects is appropriate to communicate the risk among the different stakeholders with diverse expertise?

The 3D urban visualizations models, generated in this thesis, are made with referenced geographic data by using GIS technology. In addition, the dissertation does not discuss 3D visualization as a design tool for the designers but as a communication tool to interact with disaster management stakeholders.

The efficiency of the proposed framework is evaluated by feedbacks from the users of the implementations, who are experts from the municipality and academia.

Augmented Reality (AR) allows the user to observe the real world, with superimposed virtual objects upon it. Therefore, AR supplements reality, rather than completely restore it. AR can apply to all senses, not just sight. Nevertheless, AR could be extended to include sound (Azuma, 1997). This thesis only focuses on the generation of 3D urban visualization environment for natural hazards and is not intended for the direct definitions for AR method and tools.

The conceptual framework is developed for guiding the generation of risk communication tools to be used in decision-making processes in all phases of disaster management. Figure 1.3 illustrates the role of the proposed research in the disaster management cycle.

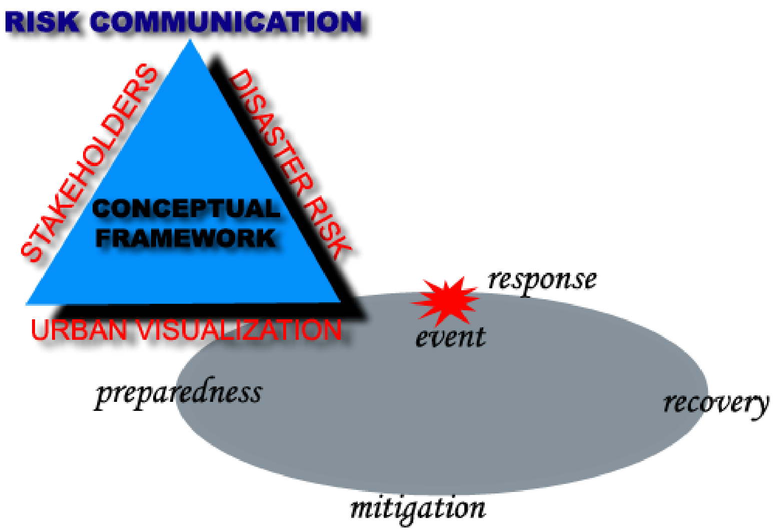


Figure 1.3. The theoretical background of the research

In the framework generation process, related headings, which cover all the concepts depicted in the figure 1.3, are analyzed. Theoretical background of the research is based on two main pillars. These are hazard-related concepts and urban-related 3D geospatial visualization concepts. Hazard related concepts are disaster management circle with related management strategies, stakeholders definitions and finally all of the disaster risk related concepts like risk assessment and risk communication. 3D geospatial visualization concepts are object definitions in the light of spatial data infrastructures, object representation ways and model generation methods. In the framework, all of these concepts are organized and used to realize the aim of the desired framework in the field of 3D disaster visualization for urban environment. Moreover, two natural hazard cases were studied to see the operational status and to find the formative feedbacks for the proposed framework.

Concepts used to form the conceptual framework are; *user*, who will use the generated communication tool, *urban objects*, which are used in 3D urban representations with a perspective of Open Geospatial Consortium's (OGC) CityGML spatial data infrastructure for 3D urban modeling and *natural hazards related components*, which constitute the context of the visualizations; and these three concepts form the visualization components. After the definition of the visualization components, the basic concepts that should be analyzed and answered are the spatio-temporal characteristics of natural hazards and the representation identification of the required urban objects for different scales. Eventually the issue of 3D urban model generation is analyzed within the implementations. The processes of urban model generation are analyzed with the dimensions of source data acquisition and the perspective of generation processes. In addition, data inquiry results are interpreted to reach the needed 3D urban model.

1.3 Organization of Thesis

The thesis includes seven chapters that cover the corresponding subjects in an organized manner. A brief description of each chapter is as follows:

Chapter 1 introduces the motivation section, which includes the explanation of visualization and natural hazard concepts, the scope of the thesis, the intended outcomes, the basic tools that are used for the study. Chapter 1 also provides the needed background information. Finally, it includes the organizational information of the following chapters. Chapter 2, which is the proposed framework, introduces the proposed disaster/risk visualization framework with the needed background information. In the third, fourth and fifth chapters, the three basic phases of the proposed framework are given with proposals suggested for the related concepts. In Chapter 3, visualization components are conferred, identification of the modeling objects that are used in the intended 3D urban models are discussed with the spatial data infrastructures view and the new Level of Detail (LoD) hierarchy that was adopted from CityGML is introduced. In Chapter 4, LoD definition decision rule, which is used to find the appropriate LoD definitions of model objects, is presented. In the fifth chapter, different 3D urban modeling methods are analyzed to compare the data and process needs and appropriate application areas for Level of Processing

(LoP) axis of the reference frame. Chapter 6 demonstrates how the framework is applied for an earthquake case in Eskisehir, and a tsunami case in Fethiye, Turkey.

The last chapter involves the conclusions and recommendations. In this chapter, the conclusions of the research are given with a discussion. Besides, the recommendations for extending and testing the framework are elaborated upon.

CHAPTER 2

THE PROPOSED FRAMEWORK

This chapter presents the proposed framework, which establishes a link between the disaster type (e.g. flood, earthquake etc.) and the components of 3D urban visualisation. The framework takes into account the modeling issues such as the appropriate detail level of the 3D model objects, the time/efforts needed to create the visualization, and the availability of software, source data, etc.

There are various framework definitions in the literature. Although the name of the dissertation imples the mentioned framework approaches, there is a need to emphasize the distinctions between different framework definitions. In computer sciences, *software framework* directly related with a reusable set of libraries or classes for a software system. The terms to framework used in this thesis corresponds to the definition of the *conceptual framework*, which is a set of theories widely accepted enough to serve as the guiding principles of research within a particular discipline.

2.1 Background

The use of 3D spatial data for all the phases of disaster management is a new but quite attractive topic in geosciences. There are several studies on the use of 3D geographic information in modeling hazard phenomenon and corresponding urban environment. The related studies are given in an order starting from those with a general view of the concepts to the more specific ones, which are directly related with the topics and discussed in the dissertation.

In Gouin et al. (2002), a survey of visualization techniques and approaches was conducted. Visualization, which forms the subject of the study, is used in allied command and control systems, which are useful for military decision support systems. The survey was applied in a manner that categorized the related visualization methods with a three dimensional framework, which is named Reference Model framework for the application of Visualization approaches (RM-Vis) (figure2.1). The Domain Context, Descriptive Aspects and Visualization Approach constitute the three axis of the proposed framework. The main aim of the study was to survey the current visualization approaches and techniques; however, a generic framework was proposed in the study. The application of the proposed framework could be expanded to all visualization areas to see the current situation and to determine the visualization method, which fits for the purpose and future directions.

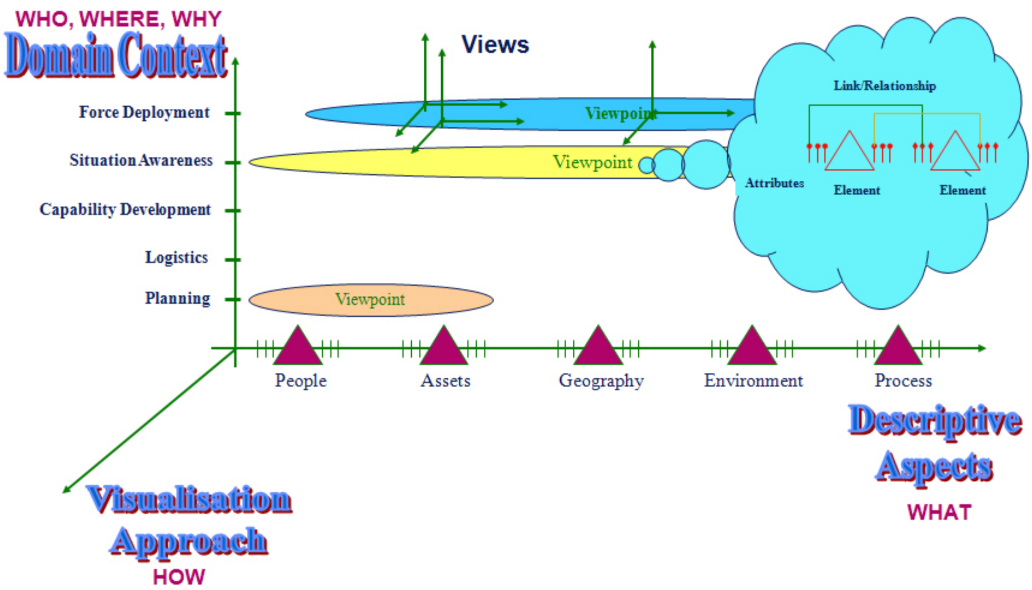


Figure 2.1. RM-Vis Framework (Gouin et al., 2004)

Sapaz and Isler (2006) put three transportation visualization examples to the reference model of Gouin et al. (2002) in order to provide a better understanding of the framework. These studies played the role of idea generator for the proposed framework. An organizational and theoretical gap was distinguished through Gouin et al.'s approach.

Usery (2000) put forward a theoretical framework for representation of the developed spatial, thematic, and temporal dimensions of geographic features. The proposed framework matches the whole concept of a geographic feature as a single, unique entity in the real world with multiple object representations. According to the framework, one geographic feature could be represented as a point at a certain resolution and as an area at a higher resolution.

Uitto (1998) proposed a framework, which uses GIS for urban disaster management considering the disaster vulnerability concept. In the proposed framework, GIS techniques are utilized to assist planning with the calculated urban vulnerabilities especially for megacities. The study is among the first ones, which approach the natural hazard risk assessment with a social touch and GIS utilization.

Herold et al. (2005) outlined a framework for establishing an online Web-based Spatial Disaster Support System (SDSS) or disaster management, and the framework integrates the concepts of GIS, Spatial Databases and the Internet for Disaster Management. In the declared framework, maps are the primary output of that system. The main argument of the paper is that the type of the discussed system must be kept simple with a consideration of skill and resource availability in developing countries.

Zlatanova et al. (2007) discussed an emergency response framework. The technical necessities of multi-risk emergency response systems were evaluated from a 3D spatial information perspective, and the proposed system architecture covers data management and communication subjects of problem areas.

Isikdag and Zlatanova (2009) proposed a framework for automatic generation of buildings in CityGML using Building Information Modeling (BIM). The framework defines the procedure of automatic building generation in a three-stage flow. In the first stage, the rules for generation are defined for semantic mapping of BIM classes to the CityGML. The second stage includes geometric simplification rules, and in the final stage the rules for the transformation of attribute information are defined.

Hizaji et al. (2010) proposed a framework for integrating the 3D BIM utilities network data into a GIS-based water utilities maintenance operations and management system. Like the proposed framework, this study also utilizes CityGML as a base model to provide an integrated ontology covering the BIM and GIS model concepts. Another contribution of the study is the demonstration of a new application area for these types of 3D urban models.

Apart from the studies related to the proposed framework, MacEachren and Kraak (2001) emphasized the need for theory in the research area of 3D representation. According to the study, the results of a team research (Mark, 1999), which focused mainly on the five issues of the visual representation (these are context, data, usage, users, and technology), pointed out five main research challenges to reach an effective visualization tool. These research challenges were;

- The main reason, to develop a theory for geo-representation and formalizing representation methods, is that the existing theory of cartographic geo-visualization is inadequate.
- To develop new forms of representation that support the understanding of geospatial phenomena and space-time processes
- To adapt representation methods to meet the changing nature of data to be represented
- To adapt representation methods to the increasing range in types of task that visual geospatial representations must support
- To take advantage of recent (and anticipated) technological advances in both hardware and data formats

These studies, however, do not provide an adequate methodology to define the level of 3D urban modeling in natural disasters for various types of natural hazards, but create a base to generate the needed framework. The most recent work mentioned above pointed out the theoretical development needs of the geo-representation or visualization research area. A conceptual framework is proposed to complement the related studies and find solutions for the research challenges mentioned in the motivation section of the disseration.

2.2 The Framework

The proposed conceptual framework provides the benefit of enhancing the effectiveness of natural hazard visualization results and this improves the cognition of stakeholders about the visualized phenomena, which results in increased risk communication. The main pillars of this dissertation, 3D visualization through GIS, has a potential for providing a better risk communication tool for visualization of natural hazard risk in urban areas and this visualization issue needs a framework to organize the associated parameters.

The proposed framework handles these parameters in a three-dimensional reference frame (figure2.2) with three basic phases.

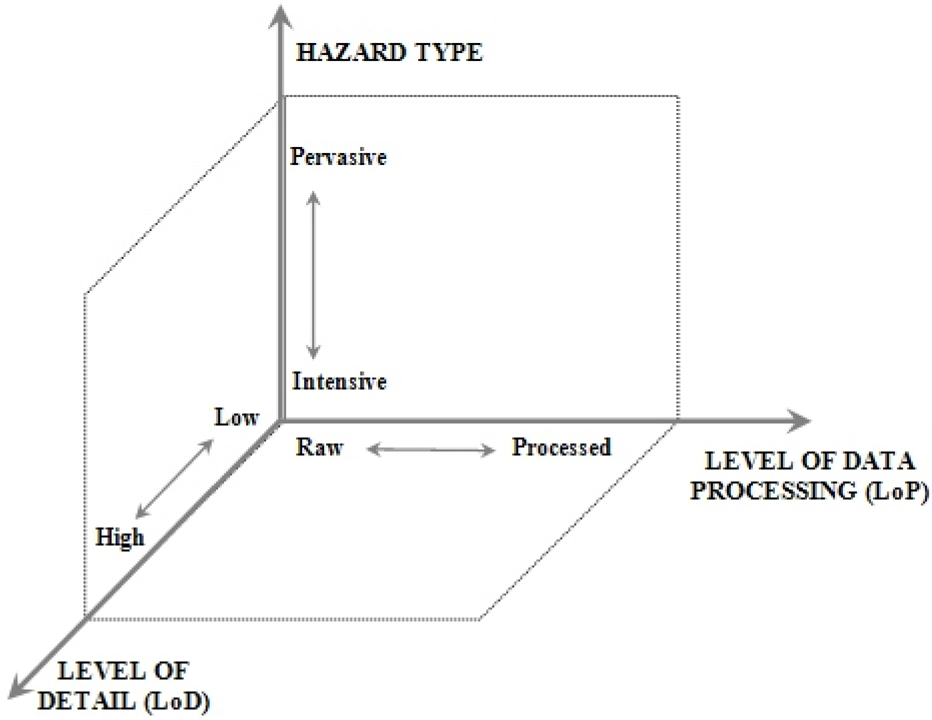


Figure 2.2. The reference frame of the proposed framework depicted with three axes of: Hazard Type, Level of Detail (LoD) and Level of Data Processing (LoP)

Initially, the data stored and used in GIS could be classified by two spatial dimensions and one attribute dimension in addition to these, in the course of time the third spatial dimension has been added by technological developments and needs in this direction. Eventually the dimension of time was added to this classification by those researchers whose main concern was temporal GIS alias TGIS (Harrower, 1999; Ott and Swiaczny, 2001; Peuquet, 2002).

The GIS data could be stored within a database with three basic elements; in other words, geographic data is characterized with three basic components. These are time, space, and attribute. In GIS, the attribute and the spatial information of the spatial objects that are stored and analyzed change through time (Castagneri, 1998). This three-dimensional knowledge approach of GIS is the main inspiration source for the proposed reference frame of the proposed conceptual framework given in figure 2.2.

Three axes of the proposed reference frame is related with the dimensions of time, space and attribute from the three-dimensional knowledge approach. In this respect, the Hazard Type (HT) axis represents the attribute dimension with its contextual effect to the framework, the Level of Detail (LoD) axis represents the space knowledge dimension because it defines the spatial representation of the modeling objects, and the last axis, Level of Data Processing (LoP), is analogous to time dimension. Actually, in the LoP axis the process load of the modeling methods is evaluated in terms of time and source costs. Then, the relation between the LoP axis and time still is not trivial. Moreover, the effect of the temporal resolutions of the used data sources is also managed in this axis.

3D urban model objects are pointed out in this three-dimensional reference frame consisting of three axes: LoD, LoP and HT. In an urban environment, with respect to a hazard type, a specific level of detail is required, which determines the level of processing for urban, urban zone or each building object by itself, depending on the scale of the assessment. This relation may be represented as a point, line, area or volume in the three-dimensional reference frame.

The HT axis of the reference frame defines "what" will be visualized and constitutes the context of the visualization (figure 2.3). The prevalence level found through the proposed LoD decision rule is used to rank the different hazard types. Hazards that have a low prevalence level are placed close to the origin, and those with a high prevalence are placed far from the origin. According to this approach, low prevalence mean that the required 3D urban model covers small areas, which refers to relatively low costs. Conversely, natural disasters with high prevalence create a need for 3D urban model for wide areas, with high operation and construction costs.

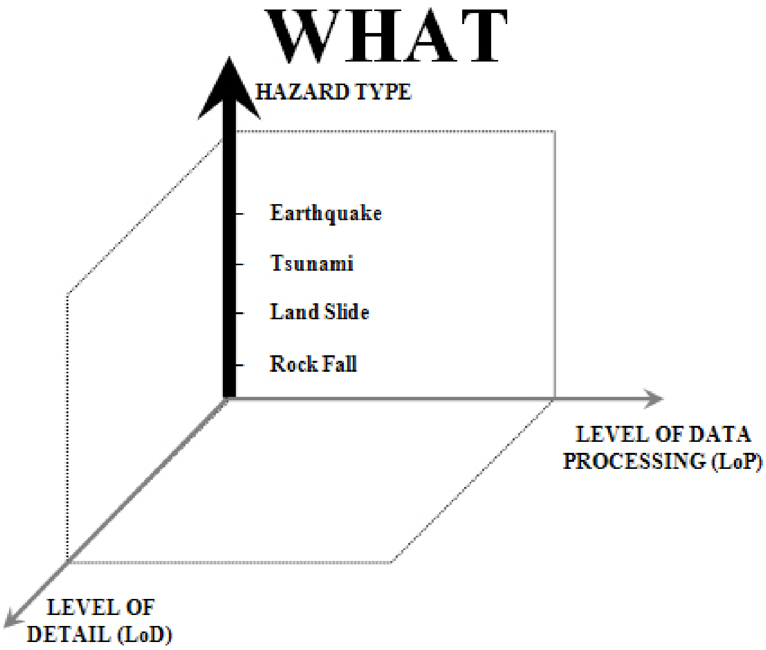


Figure 2.3. Hazard Type axis, which defines “what” is visualized

The LoD axis defines “in what form” the previously defined visualization objects will be visualized (figure 2.4). The resolution obtained from the proposed decision rule is used for finding the appropriate object representations. In this way, the HT and LoD axis are linked together. In this axis, the LoD definitions are adopted from the CityGML, and a new LoD hierarchy for indoor representations of the building objects is proposed to complement the CityGML’s LoD definitions. In the axis, general LoD definitions are placed close to the origin and the detailed ones are placed outwards on the axis.

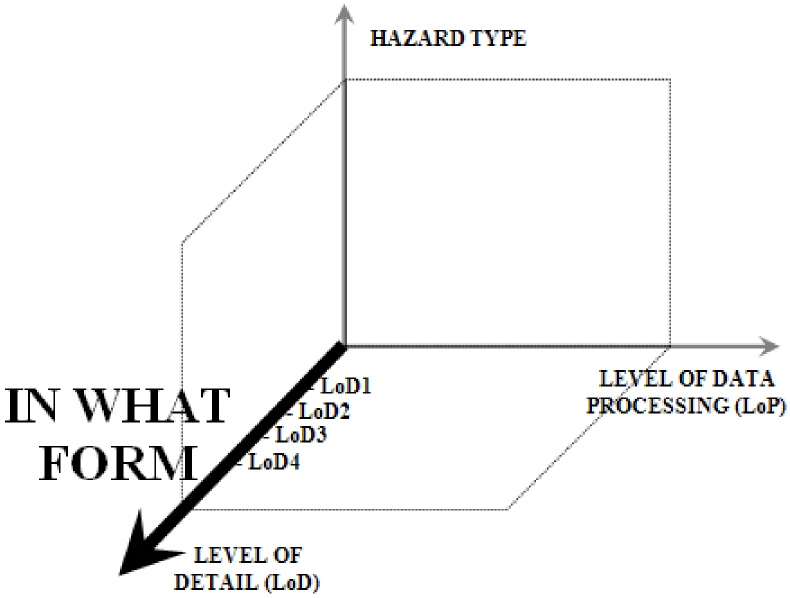


Figure 2.4. LoD axis which defines "in what form" visualization objects are visualized

The LoP axis defines "how" to prepare visualization (figure 2.5) and represents the effort required to generate the needed geometrical representation or to obtain the available data. At the moment of disaster and during the response phase of the natural disaster, temporal resolution of the information is more important than spatial resolution. In such situations, clear definitions of the data and processes need to acquire an appropriate model is vital for effective disaster management. By relating LoD with LoP, the proposed framework effectively works for all phases of the disaster management circle. In the scope of this dissertation, LoP axis is defined and alternative modeling methods are analyzed according to the data and process needs of the modeling methods, yet the relation between the LoD and LoP axes should be studied in a more detailed way and rules should be described in the future.

In the LoP axis, raw inputs like simple building box representation or course DEM for terrain representation is placed close to the origin; on the other hand, model objects requiring more processing overheads like building object LoD4 or detailed TIN model for terrain representation are placed to far away from the origin.

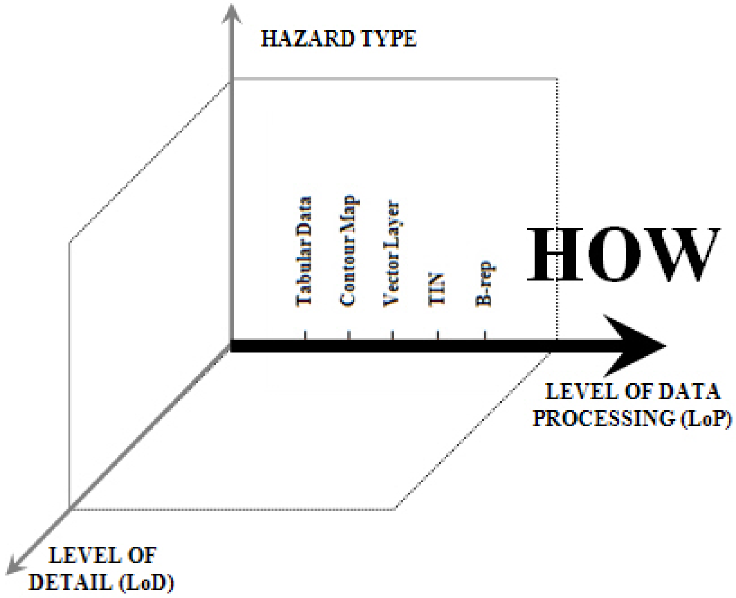


Figure 2.5. LoP axis which defines the needed visualization efforts in terms of data and process.

In the urban disaster visualisation environment, there are three main components*:* *urban objects (above ground*), *terrain objects (on the ground)* and *hazard medium*. The integration of these three components constitutes the resulting model. Each of these components has process steps, model components and related spatial data analysis techniques.

For urban objects, the process steps needed starts with digitising the bulding polygon (if the model generator has paper copy maps) or building footprint extraction (in this case, the generator has only aerial or high-resolution images). Land cover classification and building height detection from stereo pairs (in this case, building footprints exist but there is no data on height) may also be beneficial for urban object determination.

The generation of terrain objects can be performed by using contour data, stereo pairs or photogrammetric field surveys. The accuracy and the cost of the compulsory processes increase for each method, respectively.

The last component, and the context of the model, is the hazard medium. The process needed for the hazard medium originates from the characteristics of specific hazards or the aim of the visualisation. The hazard medium could be static or dynamic, and the process needs increase, accordingly.

These examples may clarify the definition of LoP; some municipalities may need to have a 3D extrusion model of a given area. To create such a model and provide it for the corresponding specialists, raw data may be needed to process flood inundation areas (if data and software are available). However, if indoor model of several buildings is required, the process needs more effort to create such an output. Processing efforts (represented by the axis LoP) start with creating the required 3D representation with data collection. Then, 2.5D terrain representations with draped aerial or satellite images can be considered but these require more effort, and therefore, come after the raw data. 3D extrusion such as façade texturing with ground images, 3D object generation and integration with the surface, automatic or semi-automatic roof construction, detailed façade modeling by using ground point clouds and detailed indoor modeling can exist at the end of this axis.

The processes that need personal experience and immature functionality require more effort and take place on the right side of the LoP axis. Automatic methods for creating an output are located on the left side. The LoP axis is evaluated through the analysis of different 3D model generation techniques.

Different modeling techniques are evaluated according to the data needed to construct the model and time / budget costs. Three of these 3D urban modeling techniques are tested in this dissertation. The tested techniques are; Narrow baseline photogrammetry, CAD-based 3D modeling and 3D model acquisition from stereo satellite images.

2.3 The Process Phases of the Framework

The proposed framework follows three basic phases to point each model object in the mentioned 3D reference frame (figure 2.6). These phases are;

1) Definition of Visualization Components
2) Object Representations
3) Needs Assessment

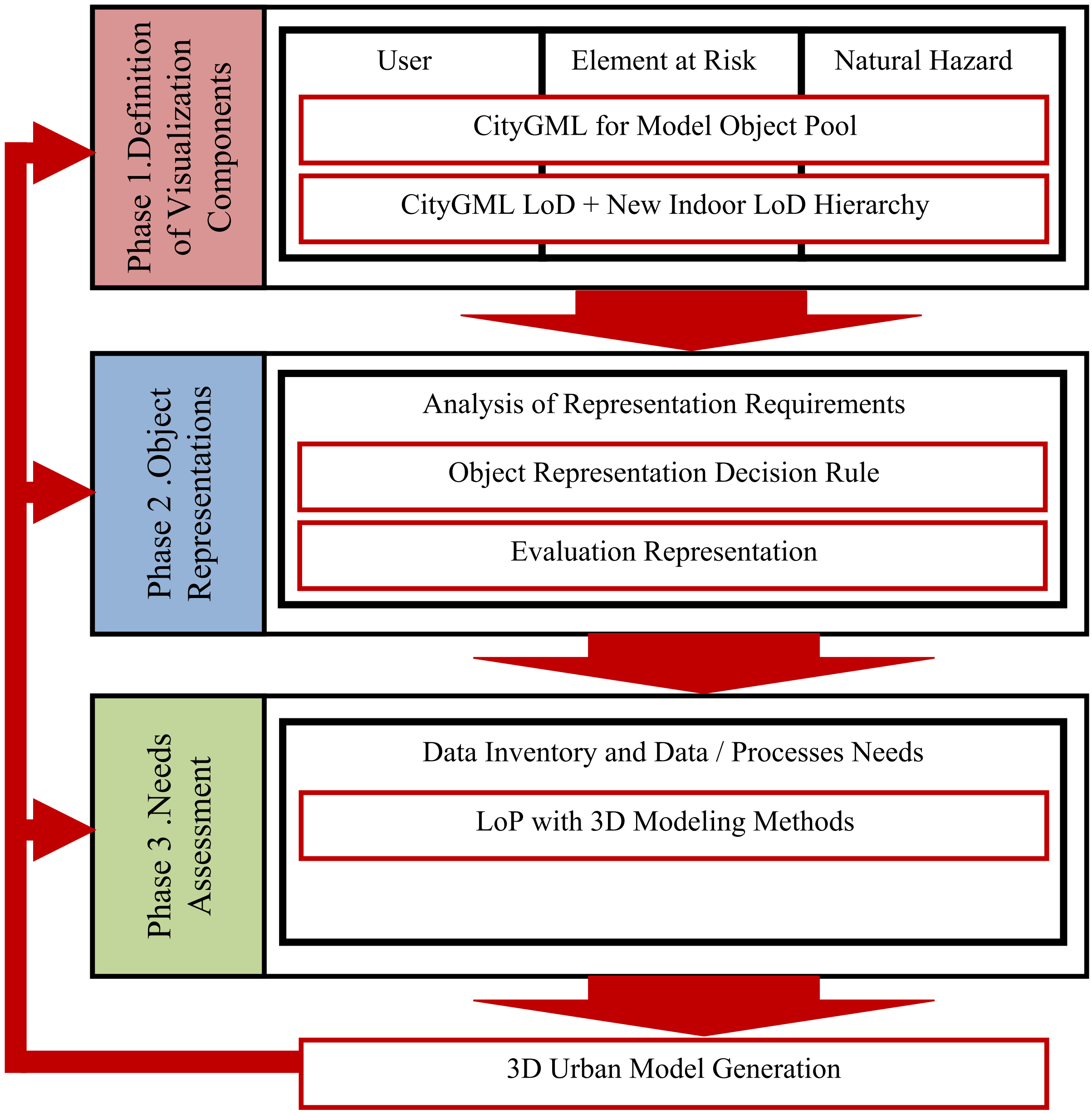


Figure 2.6. The basic phases of the proposed framework

The framework starts with the first phase, *Definition of Visualization Components*. These components are user and the related 3D modeling objects (figure 2.7); Different users might be interested in different sets of risk elements, which depend on the components of the urban environment. For example, an insurance company may have interests concerning the buildings, while utility companies might be mostly concerned with the effect on utility networks. That is to say, the objects to be considered (and included) in a particular 3D model have to be selected with respect to the user.

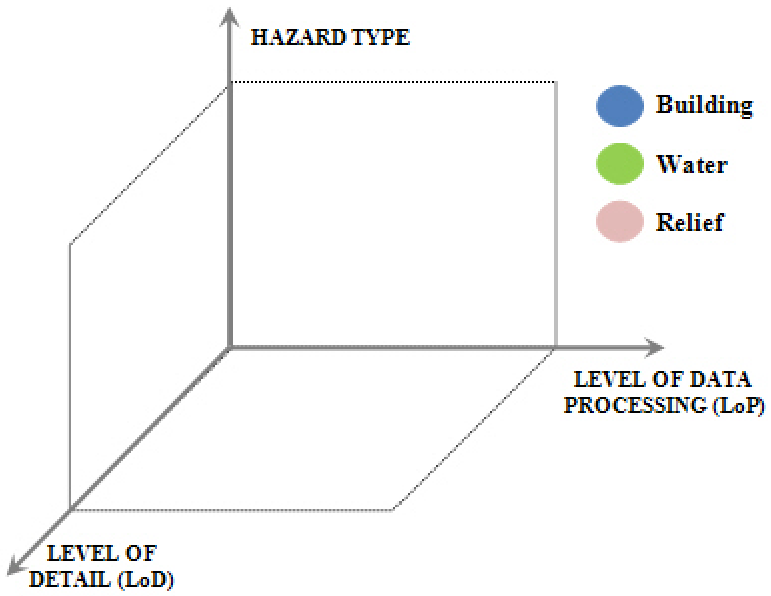


Figure 2.7. 3D urban model object in the reference frame

The second phase of the framework application is *Object Representations*. In this phase the appropriate object representations are analyzed and the levels of Indoor/Outdoor Resolution are defined by a proposed decision rule. Indoor/Outdoor Resolution defines the abstraction levels of each modeling object where low spatial resolution would mean a low LoD, while high spatial resolution would mean a high LoD. Data Representation involves the data and procedures needed for a specific model. Here, the alternatives to 3D data representations such as boundary (surface) or volume approaches (e.g. voxel) should be evaluated. In this step, natural hazard-related definitions are also completed. Hazard Characteristic Medium is the hazard-related feature in visualization, which might be the vulnerability value of any building in an earthquake case or that of an object on sea surface in a tsunami case.

In this phase, the previously defined 3D urban modeling objects are placed on the reference frame of the framework. The marked places depict the desired or required object representations of the application (figure 2.8).

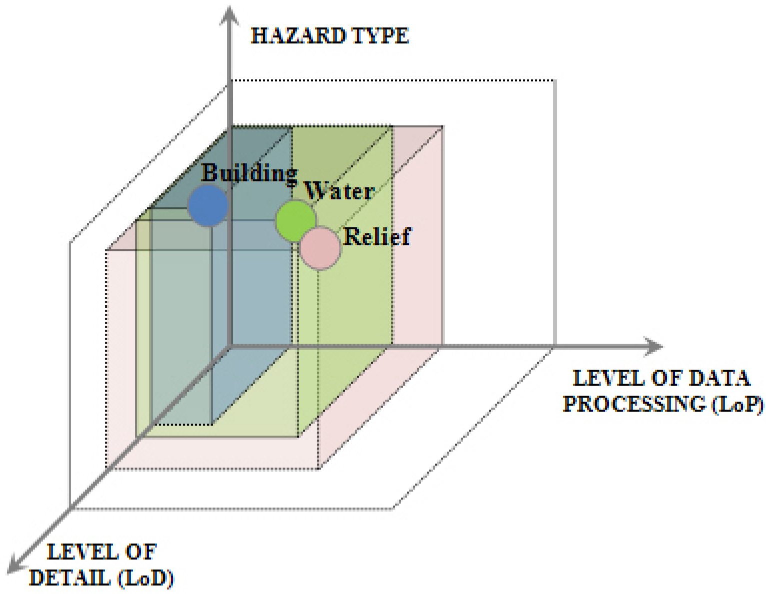


Figure 2.8. Locating points on the reference frame

When visualization objects and their LoD characteristics are defined, they are fed into the third and the final phase, which is called *Needs Assessment*. In this phase, data inventory and data / processes needs are clarified and the efforts and data needed to establish the model objects are put forward. In other words, in the first phase of the framework the points are defined; then in the second phase, these points are placed in the reference frame. Until the third phase, the framework defines the needed objects and their appropriate representations. In the third phase, the situation of the current data of practitioner is searched for with needed processes to achieve the desired representation results. In figure 2.9, the cumulative length of the lines, which connect the solid and related hollow points, is an indicator of the process load of the application (figure 2.9 is an example notation for building object). In figure 2.9, solid point, which represents the needed representation, is placed in the second phase; hollow point represents the situation of current data to reach the solid point (in the figure, only the pink object is depicted for a clearer illustration).

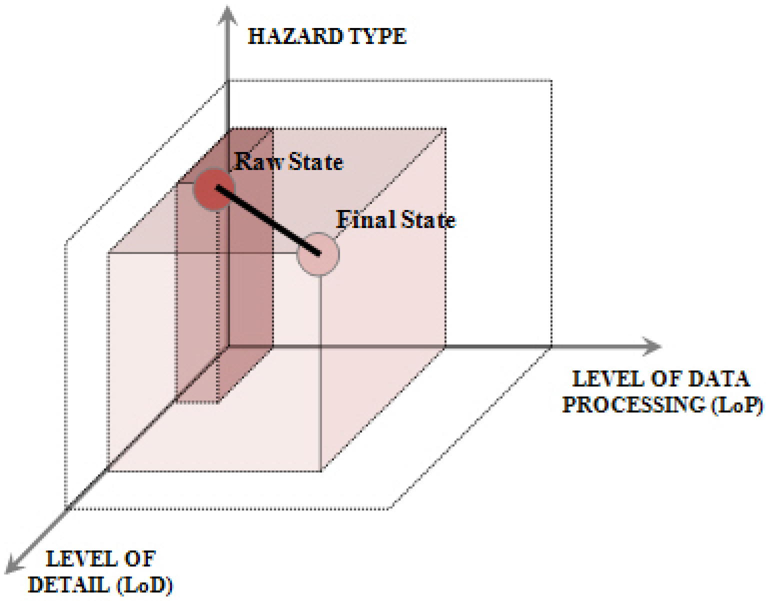


Figure 2.9. Representation of various phases in the reference frame

CHAPTER 3

DEFINITION OF VISUALIZATION COMPONENTS

A model is a certain type of abstraction. In a model, the user can understand real world processes by abstracting the world. The main concern of this dissertation is to find a trace to reach a well-balanced 3D urban model so that it is used as a communication tool for the user known in advance. The abstraction of visualized phenomenon plays a critical role in achieving a better communication as mentioned before, because there is a limit for human perception. By removing the non-essential details, users can use this limit more effectively.

In the GIS environment, the main concern of the modeling is geography, and thus the world itself. Geography consists of entities as objects and processes as models. In this chapter, the model objects, which should be determined before representation definitions about the related objects, are given through the framework.

Assets or entities, which suffer from the damage or losses of natural disasters, could be physical (people, building, or infrastructure) or abstract concepts (society or country). These physical and abstract concepts constitute the elements at risk in the disaster management terminology. An urban system covers all of these physical or abstract concepts. Therefore, the user and 3D model object definitions are completed in the first step of the framework.

Hazard component refers to the determination of two characteristics of the 3D urban model, which are *Hazard Characteristic Medium* and *Data Representation* for this hazard characteristic medium. Hazard Characteristic Medium is the hazard-related feature in visualization, which could be the tabular vulnerability value of any building in an earthquake case or a continuous sea surface object in a tsunami case.

3.1 User

The answer to the question of who will use the generated visualization tool is vital to find an appropriate visualization solution. User is the first visualization component of the framework. A user can be defined as “a person who uses an already-defined application by sitting at a workstation and interacting with it” (Hopgood et al., 1986).

In the generated risk communication tool, the term “user” involves active individuals who interact with the information rather than passive receivers. Thanks to the knowledge served by the generated 3D urban model within the GIS environment, the user can organize the visualization components better and create new information from the served visualization. Therefore, the proper generation of the visualization improves the efficiency of the interaction. The characteristics of the user of visualization can vary considerably depending on (Medyckyj-Scott and Hearnshaw, 1993):

- their ability to understand the computer conventions for the interaction
- their familiarity with the range of functions equipped in the visualization
- their cognitive, perceptual and psychomotor skills
- their expertise domains
- their expectations

Modern approaches to the generation of user-centred visualization integrate the user and the context of the visualization so as to find usable and useful tools. A user-centred design process involves the principles listed below;

- Set an early focus on users’ interest areas
- Apply a participatory design process

- Apply a user test to measure the usability
- Modify the design with user feedbacks (Gould and Lewis, 1987; Rubin, 1994)

The user stands at the centre of the visualization generation process and constitutes the starting point of the framework. In the framework, a user-centred design process (as depicted in the figure 3.1) is applied to reach an effective communication tool.

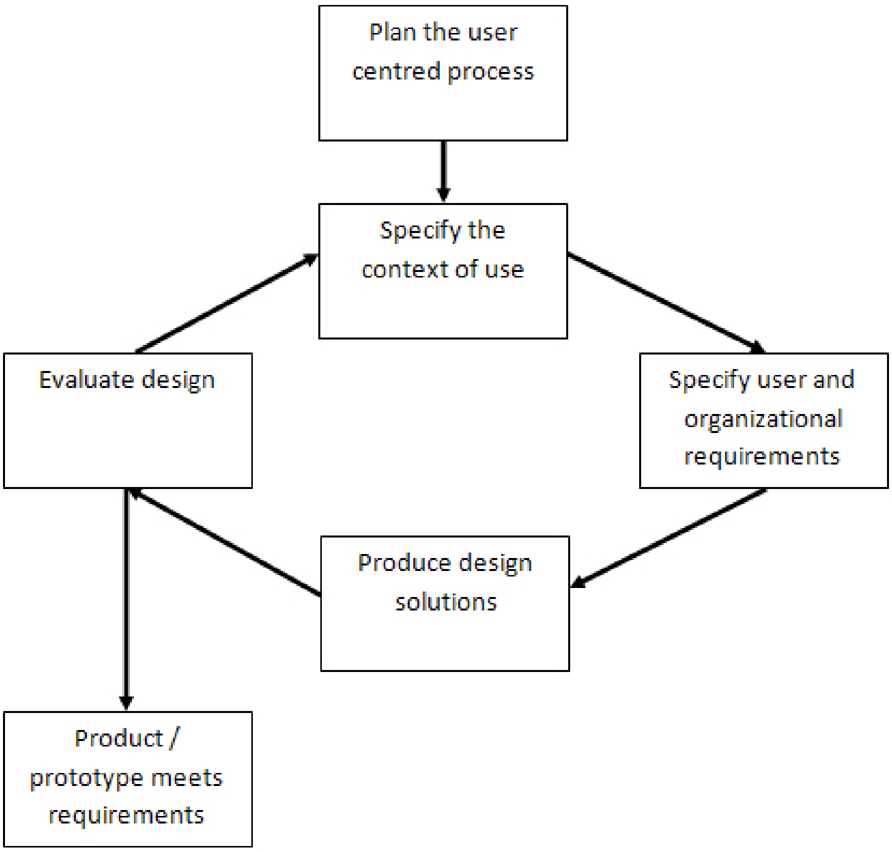


Figure 3.1. The user-centred design process (Bevan and Curson, 1999)

In the domain of urban disaster management, decision makers must be able to identify the relations between information types in order to generate decisions from heterogeneous information types. The perception of the decision makers and the visualization of the abstract information are tightly interrelated, so they must be considered and understood together. As different user groups or decision makers require different types of 3D urban models and functionalities or as the user characteristics listed above can vary in many different ways, the first parameter to be identified for the framework is the characterisation of decision makers and accordingly elements at risk.

Hazards can affect physical assets and/or humans. In an urban area, citizens, cultural heritage (e.g., buildings and natural phenomena) assets, infrastructure (e.g., roads, utility networks and rivers), and private and public housing may be vulnerable to a specific disaster and are considered to be elements at risk. Therefore, it is important to know who the user groups are and what elements at risk they are interested in. The identified elements at risk have a direct influence on the required 3D model and visualisation.

Correct determination of user group is important for determining the functional content of the 3D urban model. Different users are involved in different phases of disaster management. For example, fire fighters, medical emergency managers and the police might be the users in the emergency phase, while urban planners and risk management specialists might be the users in the preparation phase (Zlatanova et al., 2007; Zlatanova, 2008). The introduction of a fundamental classification of users is beyond the scope of this dissertation. The users considered in the framework are general users such as financial institutions (e.g., World Bank, insurance industry), academia (e.g., universities), the private sector (e.g., industrial organisations), governmental organisations (e.g., governors, municipals), civil society organisations (e.g., Red Crescent), international financial institutions and other public bodies.

3.2 3D Model Objects

To understand the urban model class definitions, urban object space should be elaborated. The urban space is object-related; these object classes contain structural "positive" elements, like buildings, and "negative" ones, such as public areas. There are objects and sub objects (figure 3.2). For example, the description of a street consists of the surrounding buildings, in addition to the geometrical information about the height of the curb and the sewerage cover. All these sub objects combine information about geometry and material (texture, color), which should be available or has to be defined (Köninger and Bartel, 1998).

Figure 3.2. Positive and negative elements of urban space

There are three main groups of modeling objects introduced in this section. These urban objects might be damaged from the related natural hazard as elements at risk, hazard-related part of the visualization in the hazard-related components subheading and finally landscape component, which is a natural part of a 3D urban visualization.

3.2.1 Elements at Risk

In the relevant urban context, building objects constitute the main elements at risk. Spatial Data Infrastructures (SDI) provides the appropriate framework to integrate all the potential data sets. Various initiative concepts exist to define the objects of interest in urban areas. Building-centered SDI could be categorized according to scale on which the infrastructure is mainly settled and the information which the infrastructure provides.

The Industry Foundation Classes (IFC)

The Industry Foundation Classes (IFC), developed by International Alliance for Interoperability (IAI), is a standardized exchange format for Building Information Models (BIM) (IAI, 2007). IFC has been designed especially for detailed building models with such elements of the building objects as exterior walls, interior walls, floors, doors and windows, ventilation, plumbing and electrical infrastructure etc. (figure 3.3).

Figure 3.3. IFC model example with electrical and plumbing infrastructure elements (IAI, 2007)

Unlike CityGML, the main aim of the IFC's BIM is to support the whole lifecycle of the building development processes such as design, planning, construction, management, and destruction. IFC serves as a common information model structure for a group of users like designers, architects, manufacturers, facility managers, etc.

The unique characteristics of the BIMs are:

- Object-oriented: BIMs have an object-oriented nature
- Data-rich / Comprehensive: BIMs are data-rich and they contain all physical and functional characteristics of the building
- Three dimensional: BIMs represent the geometry of the building with a 3D representation

- Spatially-related: Spatial relationships between building elements can be maintained
- Rich in semantics: BIMs maintain a high amount of semantic (functional) information about the building elements
- Supports view generation: BIMs support view generation (Isikdag and Zlatanova, 2009)

IFC models are encoded with EXPRESS data description language. However, an XML-based encoding ifcXML exists, and thanks to this XML-based encoding language, the interoperability of the models can be enabled. Therefore, the 3D model design software could use IFC models to create the visualization environment or modify the models. Most of the CAD vendors provide import and export functionality for IFC models (Döllner and Hagedorn, 2007)

In the framework, IFC can play the role of a source of detailed architectural building models with internal and technical infrastructure information. The main area of concentration for CityGML is 3D information model for a region; therefore, it mostly covers a huge amount of buildings, the same situation is valid for the proposed framework. In most of the natural disaster situations, natural hazards affect more than a group of building. Besides, the framework deals with not only the building objects but also terrain, street objects, vegetation and water objects. CityGML covers all of these object definitions. As a result, object taxonomies of the CityGML constitute a base for object pool in the framework and if available, IFC BIM is an information source particularly for the detailed building objects, which are the main concerns of the desired 3D model.

Benner et al. (2005) is an example for the automated transformation of IFC to CityGML. In this study, the Karlsruhe Research Center transformed both block model (LoD1) and a detailed airport facility model (LoD4). Figure 3.4 is an example of a detailed IFC building model.

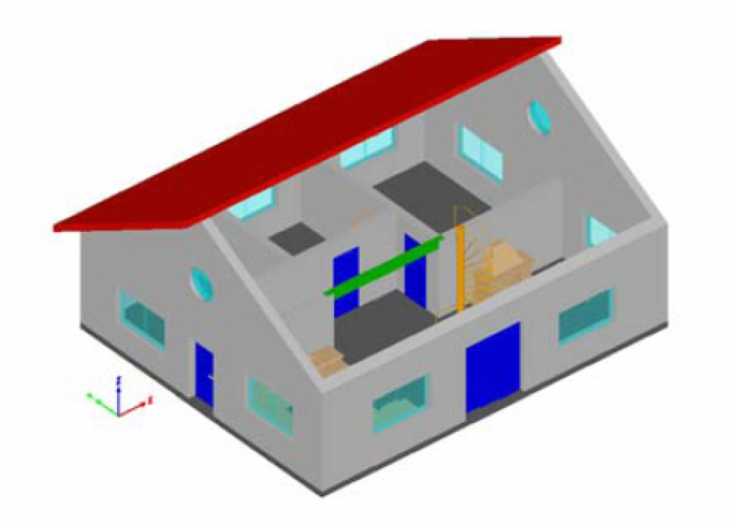


Figure 3.4. Detailed IFC building model (Benner et al., 2005)

From the view of data representation field, IFC supports various types of 3D-shaped representation methods, yet CityGML only supports B-Rep. Consequently, certain types of information like curved geometries or physical quantities could not be directly converted to the CityGML.

CityGML

CityGML is one of the few 3D urban modeling concepts, which consider two aspects of 3D urban modeling in a generic sense (i.e. it is not application-oriented). These are syntactic and semantic aspects. CityGML is a 3D urban spatial data infrastructure. It is implemented as an application schema of the Geography Markup Language 3 (GML3) of the Open Geospatial Consortium (OGC). GML3 is based on OGC's ISO standards, which means that it is open and vendor-independent.

Syntactic and semantic interoperability is necessary for each GIS component. By using an XML-based language, syntactic interoperability is achieved. Semantics is related with the geometrical and topological aspects of 3D city models and these are covered by class definitions of CityGML (figure 3.5). All basic urban model components, that is, buildings, vegetation objects, water bodies, transportation facilities (like streets and railways) and city furniture, include this class taxonomy.

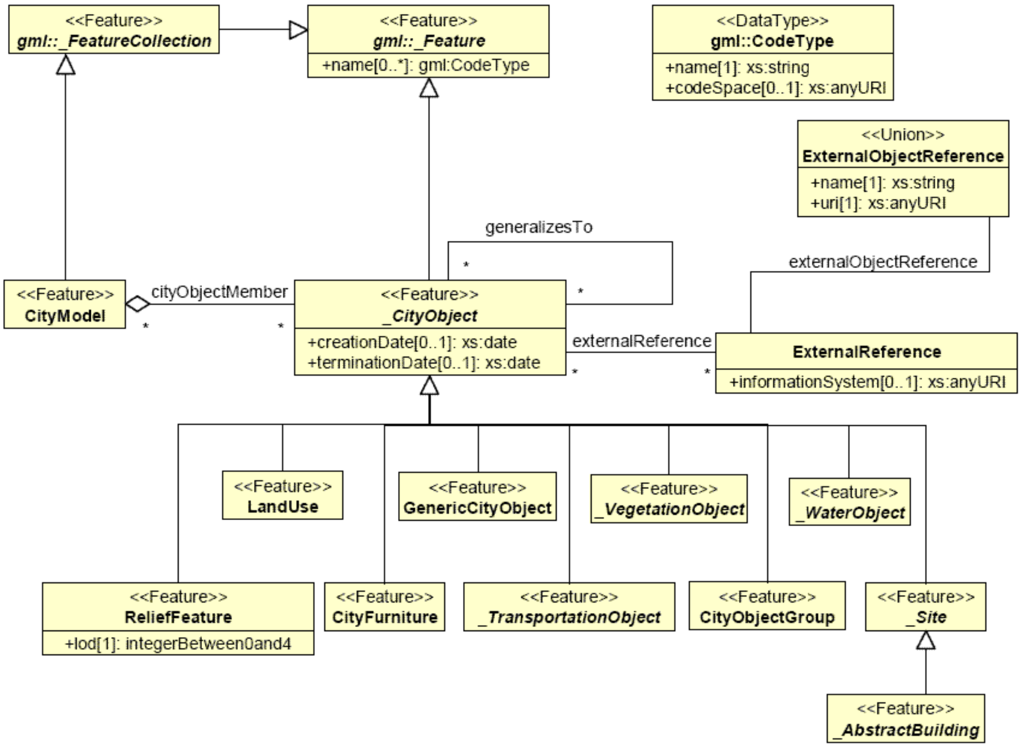


Figure 3.5. The UML diagram of the top level class hierarchy of CityGML (source: Cox et al., 2004)

The urban objects in CityGML are subdivided into certain class definitions. One of the important classes is the building class, which provides the representation of thematic and spatial aspects of buildings. Another one is relief, which is simply the terrain. The others are transportation, which represents the objects of all modes of transportation, for example a road, a track, a railway, or a square, and land-use, which describes those areas of the Earth's surface dedicated to a specific land use.

Several other objects such as city furniture, vegetation and water can also be useful for risk management. The city furniture objects are stable objects like lanterns, traffic lights, traffic signs, advertising columns, benches, delimitation stakes, or bus stops. The vegetation is used to represent solitary tree 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 classes compose the object pool in the framework. A set of objects important for any particular disaster can be obtained from this pool. The only limitation is the lack of underground objects. However, ongoing research and developments are considering extensions in this direction (Emgard and Zlatanova, 2008; Tegtmeier et al., 2008), which can later be included in the framework. These object classes compose the object pool in the framework. A set of objects important for any particular disaster can be obtained from this pool.

Levels of Detail (LoD)

3D semantic urban modeling is an important factor to be considered during the development of the framework. Although various aspects of 3D modeling can be accounted for in the proposed framework, the types of objects to be modelled, their representation and the resolution, or Levels of Detail (LoD), play the most critical roles in 3D urban modeling for natural disaster situations. In practice, the concept of LoD can be directly related to the resolution, hence the identification of objects in 3D modeling.

The abstraction, which is converted into visible representations, is called LoD. Studies on LoD target the reduction of software and hardware difficulties to display a large collection of urban data. To meet the needs of real-time display, it is the best choice to generate as many LoD definitions as possible in advance and to store them in the database. Nevertheless, due to the data redundancy and the storage limitations, generally only discrete LoD hierarchies are defined (Lin and Zhu, 2005). Improvements in users' spatial perception can be achieved by LoD models (Chang et al., 2007; Vanegas and Aliaga, 2009). CityGML provides the concept of a LoD for 3D urban visualizations, which is best developed for buildings. However, the approach of CityGML is appropriate for the introduction of LoD levels for various other objects. In CityGML, LoDs range from LoD0 to LoD4. LoD0 is the 2.5D level, over which an aerial image or a map may be draped (Kolbe et al., 2005), for a simple box model defines buildings in LoD1, while buildings in LoD4 are defined even with interior details of them (figure 3.6). Naturally the resolution increases from LoD0 to LoD4 (Gröger et al., 2006). The concept of LoD is quite generic and suitable for small to large area applications. The concepts of LoD of

CityGML are adopted as a starting point in the study. Table 3.1 represents the provided 3D point accuracy and the model scale descriptions of the LoD's.

Table 3.1. LoD 0-4 of CityGML with its accuracy requirements (source: Albert et al., 2003)

	LoD0	LoD1	LoD2	LoD3	LoD4
Model scale description	regional, landscape	city, region	city districts, projects	architectural models (out-side), landmark	architectural models (interior)
Absolut 3D point accuracy	lower than LoD1	5/5m	2/2m	0.5/0.5m	0.2/0.2m
Roof form/structure	no	flat	roof type and orientation	real object form	real object form
CityFurniture	-	important objects	prototypes	Real object form	real object form
SolitaryVegetationObject	-	important objects	prototypes, higher 6m	prototypes, higher 2m	prototypes, real object form
PlantCover	-	>50*50m	>5*5m	< LoD2	<LoD2

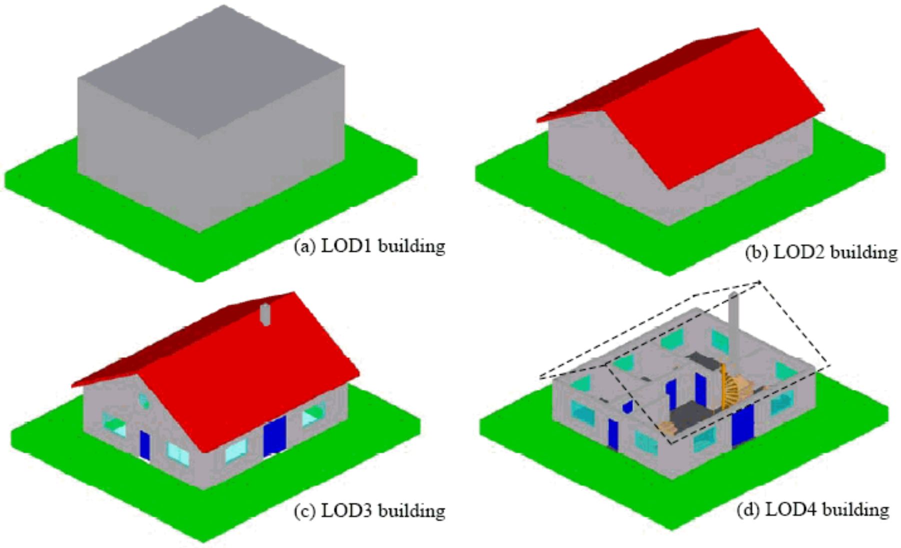


Figure 3.6. The four LoD definitions of building objects by CityGML (source: Gröger et al., 2006)

Proposed Building Indoor LoD Hierarchy

Currently, building LoD definitions of CityGML is robust and steady especially for the external parts of the city structures (figure 3.7). The same situation does not apply to the indoor representation definitions. In the LoD 4 of CityGML, indoor detail is defined as;

> *"LoD4 completes a LoD3 model by adding interior structures for 3d objects. For example, buildings are composed of rooms, interior doors, stairs, and furniture."*

This definition characterizes a building model that has all the architectural details in the most detailed representation level.

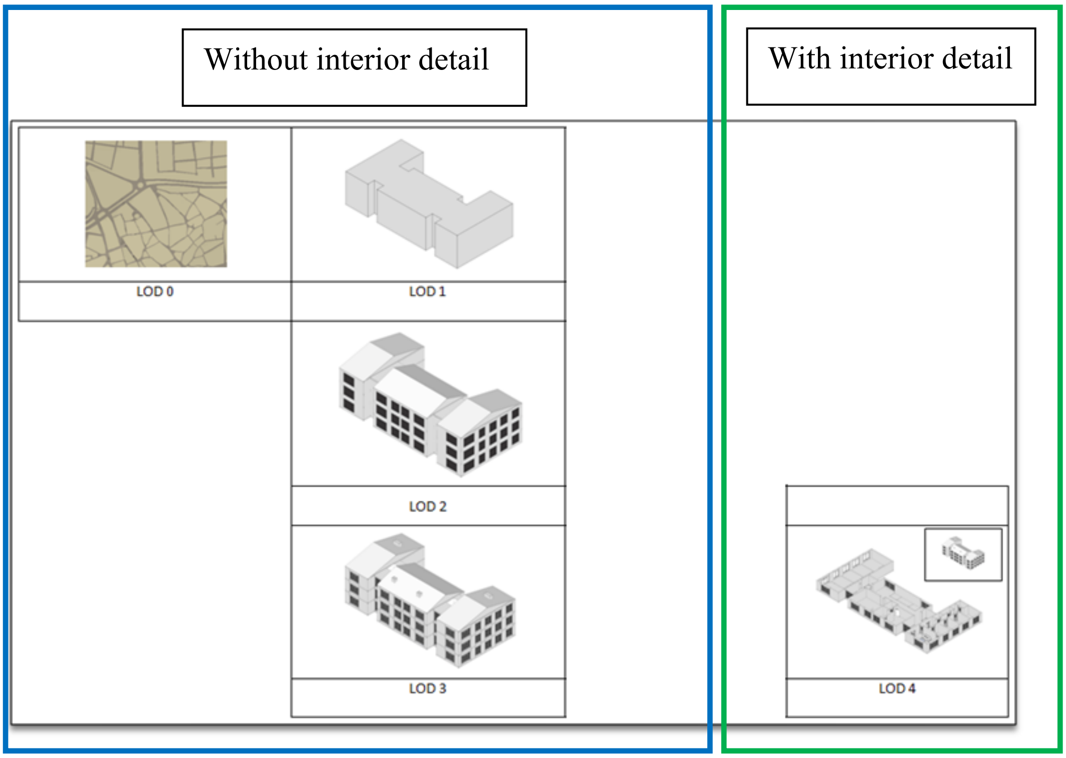


Figure 3.7. The current LoD hierarchy of CityGML

The main concern of the framework and the applications is finding the proper representation especially for building objects of the urban models for different disaster situations. In this context, more detailed approaches are needed to improve the efficiency and the communication capability of the generated 3D urban model in all phases of the disaster management. Pre-hazard phases, which are preparedness and mitigation, need to put forward the situation in more detail in the related scale. For example, the social conditions and accordingly, the resilience of all the residents in a high-rise apartment blocks are not the same, particularly in Turkey. Therefore instead of whole building representations, more detailed representations such as floor level or living unit level are more beneficial for the development of more coherent strategies in the preparedness phase.

Some natural disaster management applications need indoor LoD definitions that are more general than CityGML LoD 4 in different phases of disaster management circle.

Apart from disaster management, 3D urban models constitute spatial visualization or analysis environment for many other application areas like cadastre, planning, traffic, tourism etc. The large extent of the application area and the developing technology urge that more research is carried out about standardization for the interoperability issues. These are certain application areas that come to mind in the first place. Further application areas may also take advantage of an indoor LoD hierarch. As it was mentioned in the previous parts, spatial data infrastructures provide the rules of the required interoperability environment. Moreover, the CityGML of the OGC is a standard that focus on the 3D urban models. The proposed indoor LoD hierarchy is considered together with CityGML to improve the existent standards.

In the 3D urban modeling literature, the subject of the indoor LoD is usually handled under the general 3D urban information meta-model approaches. According to Billen et al. (2008), a unique building object can contain sub-units, which have different attributes in the thematic, administrative and cadastral senses. Consequently, there should be indoor LoD definitions as for the outer parts. Their indoor LoD definitions have three different generalization levels (figure 3.8). In LoD1, generalized polyhedrons take place if these generalized polyhedrons have some openings at LoD 2, which link up the internal sub-spaces, and at the most detailed indoor LoD definition, LoD3 has an identical opening but there is no generalization at this time. At the end, these three indoor LoD definitions are connected to the LoD4 of CityGML.

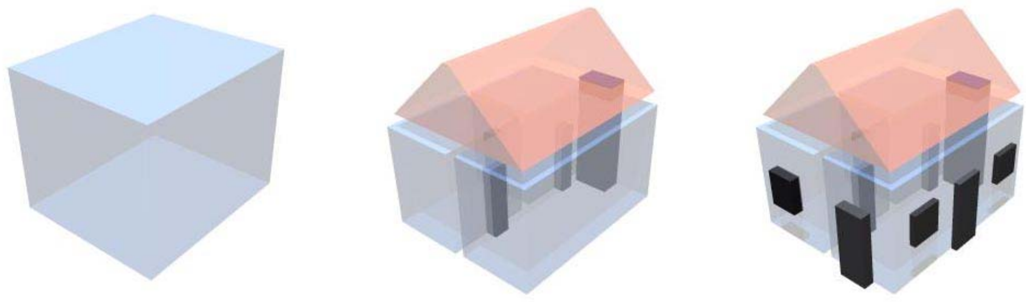


Figure 3.8. Building indoor LoDs (Billen et al., 2008)

Zhu and Hu (2009) drew a house property-oriented framework. They mentioned a weak side of CityGL in their study. According to Qing and Ming-Yuan (2009), CityGML is a good abstract framework for 3D building geometry. On the other hand, CityGML's semantic definitions are limited to just structural components (room, window, door etc.), but not real property objects like storeys or living units. This semantic classification approach is the same approach as the one adopted in this dissertation, which forms the basis of the indoor LoD proposal. The hierarchical geometric LoD framework outlines indoor and outer detail definitions in a three-level framework with five different LoD definitions. This three-level geometric framework, which starts with 2,5D horizontal level for horizontal partitioning on land block scale in the LoD2 of their framework vertical partitioning, constitutes the main concern and this level is named as the vertical level. Finally, at the third level, which has the most detailed model object definitions, indoor LoD definitions are located. The name of this level is 3D interior level, which has three different indoor LoD definitions. LoD3, the first level of 3D interior levels, has storeys e.g. within a residential building. LoD4 is described with minimal spatial portions of real property unit (living unit). Finally, the definition of LoD5 of this framework corresponds to the LoD4 of CityGML, involving indoor details with entire details like roof, walls, doors and windows (figure 3.9).

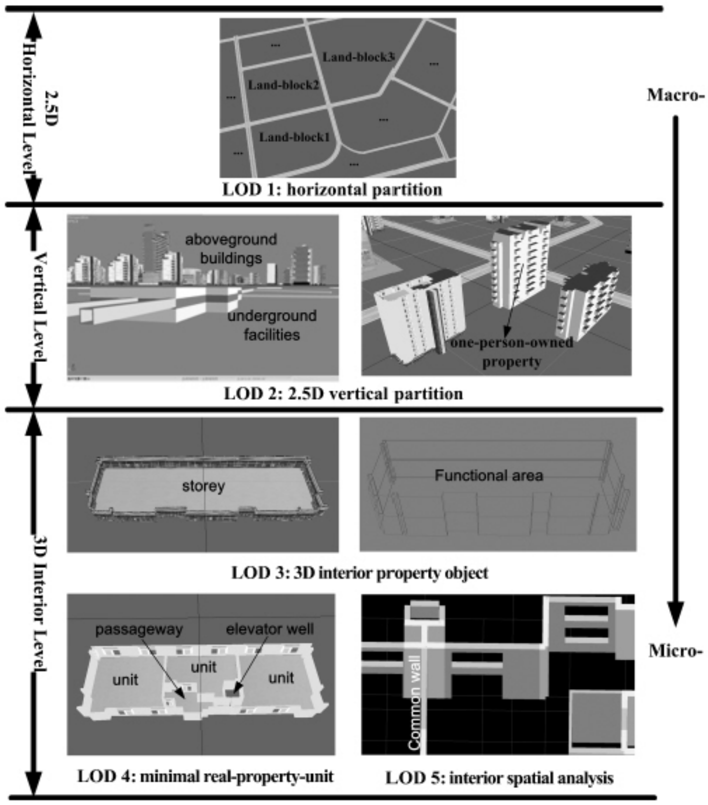


Figure 3.9. Zhu Qing and Hu Ming-Yuan 2009, the description of hierarchical levels of detail

Yuan and Zizhang (2008) propose a framework by combining Building Information Modeling (BIM) and 3D GIS capabilities for indoor navigation. BIM is an information-rich model for building generation and management. It covers 3D geometry and semantic definitions like CityGML. 3D urban models are used to generate graphs that are used for indoor navigation.

Karas et al. (2006) also use 3D building models as the main input for 3D graph generation. 3D indoor navigation or network analysis applications could be a key element for the response phase of the disaster management circle. The outputs of such an analysis can reduce the time spent by search and rescue teams; besides, escape routes, which might be communicated to the community in the preparedness phase, can be a lifesaver for large numbers of people. The proposed indoor LoD hierarch can be adapted to these types of 3D graph generation algorithms. Rougher detail levels could be beneficial for upper-scale disaster management applications.

Billen (2000), Billen et al. (2008), and Zhu and Hu (2009) stated different definitions of urban abstract space apart from urban physical object definitions. In an urban-related visualization, the discrimination of the thematic subdivision on a separate building object could be more important than the physical components. The depiction of urban object composition given in Billen (2000) is a good example. According to this study, urban space is subdivided into two, urban abstract space and urban physical space. Current spatial data infrastructures mainly focus on urban physical space definitions, but under the concept of urban abstract space, thematic, cadastral and administrative subdivision definitions could be done (figure 3.10).

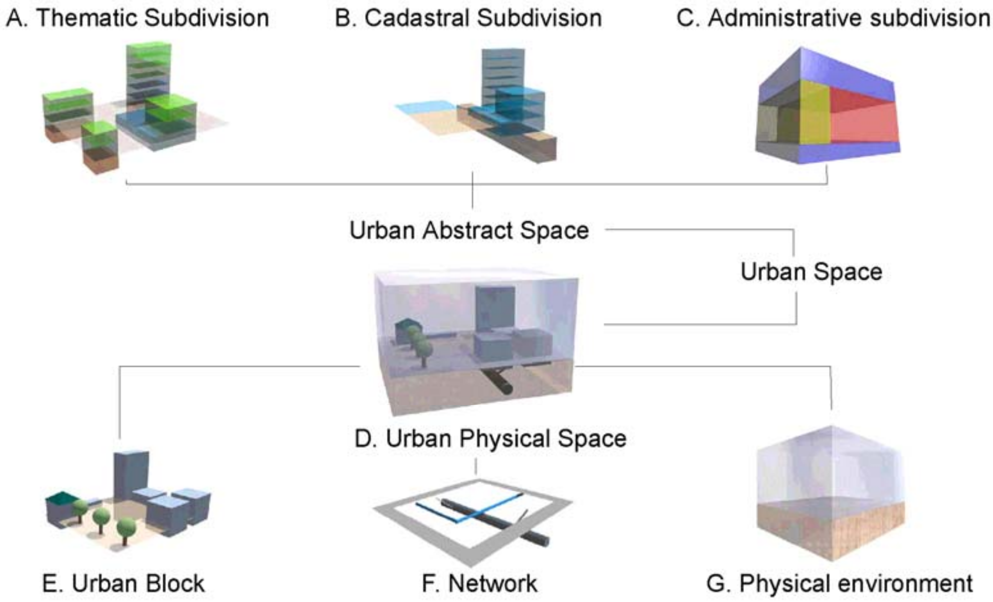


Figure 3.10. Some physical and fictious objects composing the urban space (Billen, 2000)

In an urban space, these types of abstract definitions can be increased, but generally, thematic subdivisions originate from the cadastral subdivisions, which mean that different areas with varing theme are owned by different holders and an inherently administrative status automatically emerges. For this reason, the thematic subdivision of urban abstract space are considered for the basics of the proposed indoor LoD hierarchy.

The proposed indoor LoD definitions are fully integrated with the LoD definitions of CityGML. Its notations are parallel with five level definitions of LoD. In LoD0, there is no 3D, thus the indoor definitions start with LoD1 with indoor which is denoted as LoD1,5 to LoD3,5. There is no LoD4,5 because LoD4 already covers the indoor details (figure 3.11).

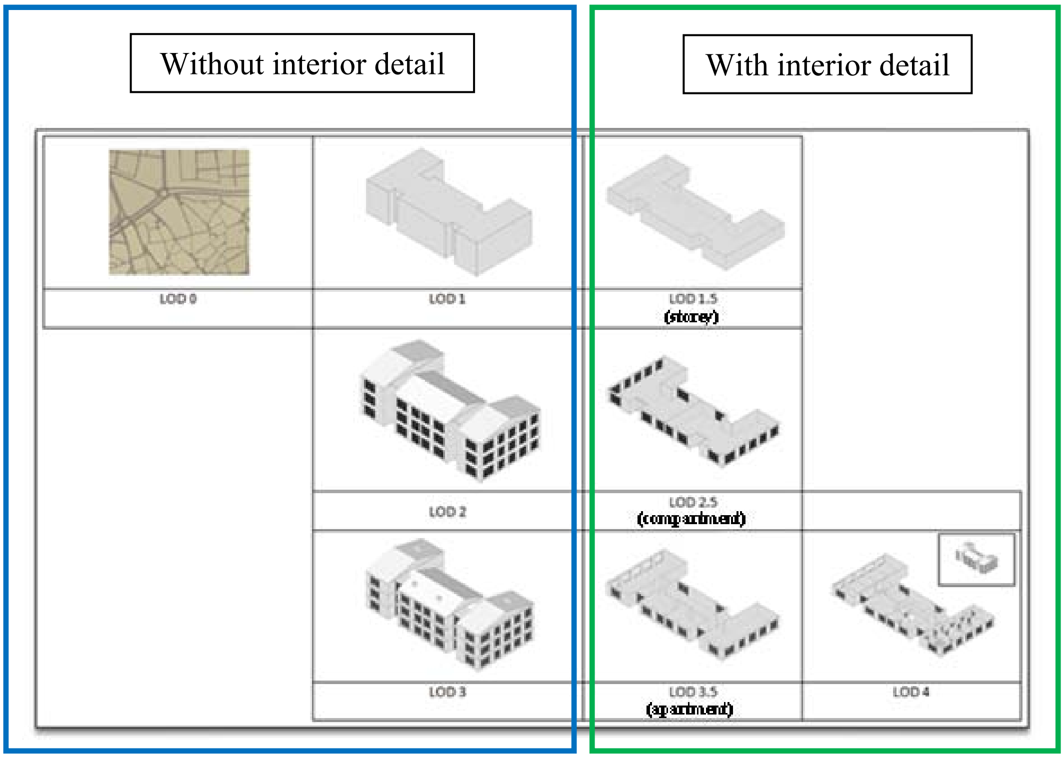


Figure 3.11. The proposed LoD hierarchy with indoor representations

In the proposed LoD hierarchy, each of the LoD1, LoD2 and LoD3 outer detail definitions is associated with the related indoor definition and notated with a half after the integer part, for instance, for LoD 1 with indoor. Semantic definitions are performed with real building objects, which are;

- LoD1 with indoor notated as LoD1,5, the corresponding building object is storey (figure 3.12)

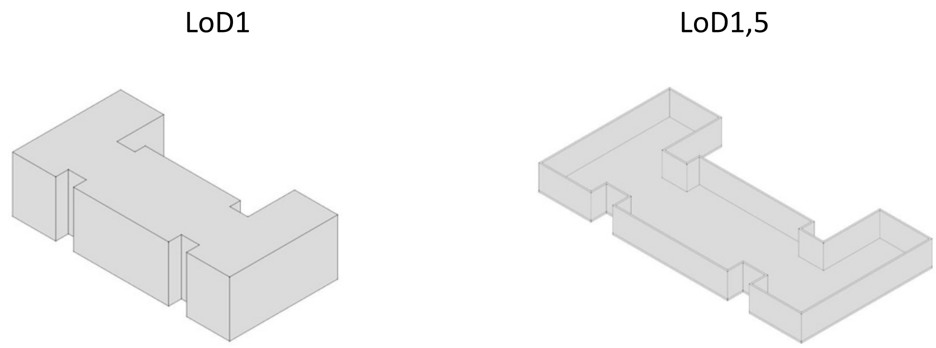


Figure 3.12. A sample representation of LoD1 building outdoor and the corresponding indoor representation

- LoD2 with indoor notated as LoD2,5, the corresponding building object is compartment (figure 3.13)

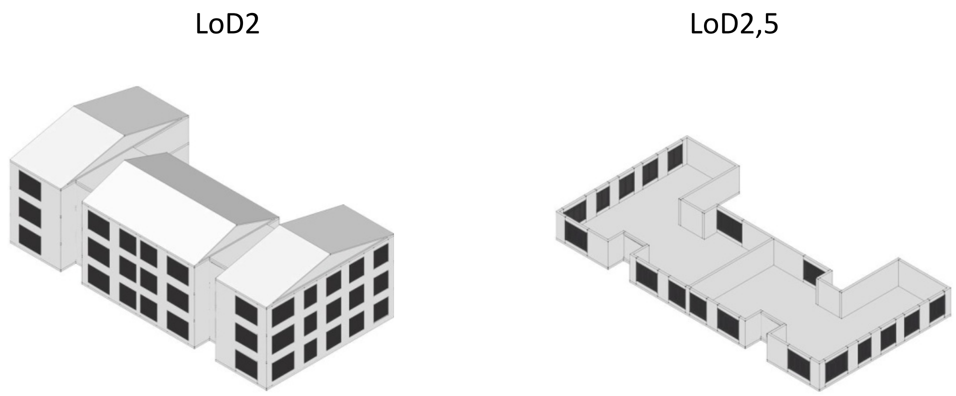


Figure 3.13. A sample representation of LoD2 building outdoor and the corresponding indoor representation

- LoD3 with indoor notated as LoD3,5, the corresponding building object is apartment (figure 3.14)

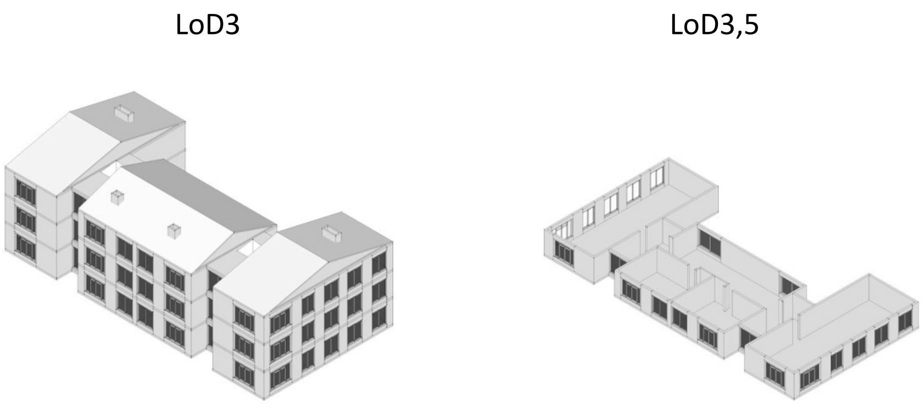


Figure 3.14. A sample representation of LoD3 building outdoor and corresponding indoor representation

- The demonstration of LoD4 on the same sample building representation could be similar to figure 3.15.

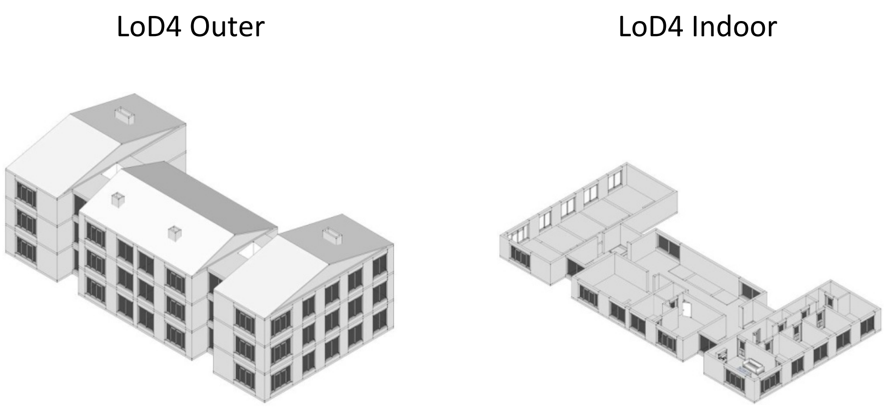


Figure 3.15. The same building with LoD4

Indoor LoD is controlled by the parameter “i” in the object representation definition decision rule, which is described in the next chapter. If there is an indoor penetration, decision rule is taken into account by adding a half to the integer LoD result. The “i” parameter may also be used if there is an indoor detail request by the user.

3.2.2 Hazard Related Components

Natural hazards constitute the context of the intended 3D urban model obtaining the correct characteristic features by using the proposed framework as a communication tool. Therefore, the hazard-related components are the main ingredients of the framework and handled in the first step together with the user and elements at risk definitions of the visualizations.

The hazard-related components are represented by the hazard characteristic medium in the framework. The hazard characteristic medium could be an entity represented by an object (e.g. as in the Eskisehir Earthquake application; hazard characteristic medium is the vulnerability index value of each building, which is an abstract entity). On the other hand, in some natural hazard visualization applications, it might turn out to be a process represented by a model (e.g. as in the Fethiye Tsunami application; hazard characteristic medium is sea surface, which is a process figured out by mathematical models).

Physical modeling represents the design and operation of systems that are based on or derived from physical phenomena (in this case natural hazards). The modelled phenomena can have different processing characteristics, such as mathematical, data driven (layer-based analogue map or GIS) or a combination of both. According to another definition of modeling, with respect to the processes, models have two different points of view. In the first one, a set of independent elements and any kind of relation between these elements are described; this view of model is described as the static model. In the second one, which is the dynamic model, the behaviour of related elements is described over a period. If the sample applications are assessed according to these definitions, the first could be classified as a static and the second as a dynamic model application. The process modeling approach of the natural hazard visualization cases is used to define the data representation of hazard characteristics medium. For example, if the process uses a mathematical model, complex data representations like voxel-based volume modeling technique may be needed. Static models, which can be given as description of a set of object and relationships, might require using boundary models.

These two different points of view define the hazard characteristics medium representation; at the same time it also defines the needed data indirectly, for the temporal resolution of the data needed is denser in the dynamic view than in the static view. Table 3.2 gives the required data items and their spatial and temporal resolutions.

Table 3.2. Earthquake and Tsunami risk assessment processes and data needs with spatial and temporal resolutions, (adopted from Van Westen and Georgiadou, 2001 and Yalciner et al., 2005)

Disaster	**Risk assessment Process**	**Data type**	**Spatial resolution (m)**	**Temporal resolution**
Earthquake	Structural	Historical events	10 - 1000	Days
		Faults	5 - 10	Decade
		Land use	1 - 10	Years
		Lithology	30 -100	Decade
		Soil mapping	10 - 30	Decade
		Geomorphology	1 - 10	Decade
	Physical accessibility	Road network	1-10	Years
		Average speeds	1-10	Years
		Emergency service locations	1-10	Years
	Socio-economic parameters	Economic	1 - 10	Years
		Demographic	1 - 10	Years
		Social	1 - 10	Years
Tsunami	Generation	Faults	5 - 10	Decade
		Historical events	10 - 1000	Days
		Geomorphology	10 - 30	Years
	Propagation	Bathymetry/topography	1-10	Years
		Rupture characteristic	10 - 1000	Days
	Run-up	Land use	10-1000	Months
		Detailed topography	0.1 - 1	Months
		Slope movement	0.01	Days

Although natural hazards affect urban areas, they have different underlying processes operating in Earth's system, which should be considered in the framework. For example, earthquakes develop beneath the surface of the Earth, landslides occurs on the earth surface as meteorological hazards (e.g. windstorms) develop in the air and floods and tsunamis develop in the water. Type of natural hazard is used for hazard characteristic medium definition.

The relation of the hazard processes with the utilized visualization platforms is depicted in figure 3.16. According to this operation flow, the results of the disaster simulation models are integrated into the visualization environment as a base for the other spatial database objects like buildings. In the implementation section of the dissertation, case study applications are conducted by using such a workflow to integrate hazard medium and urban model objects.

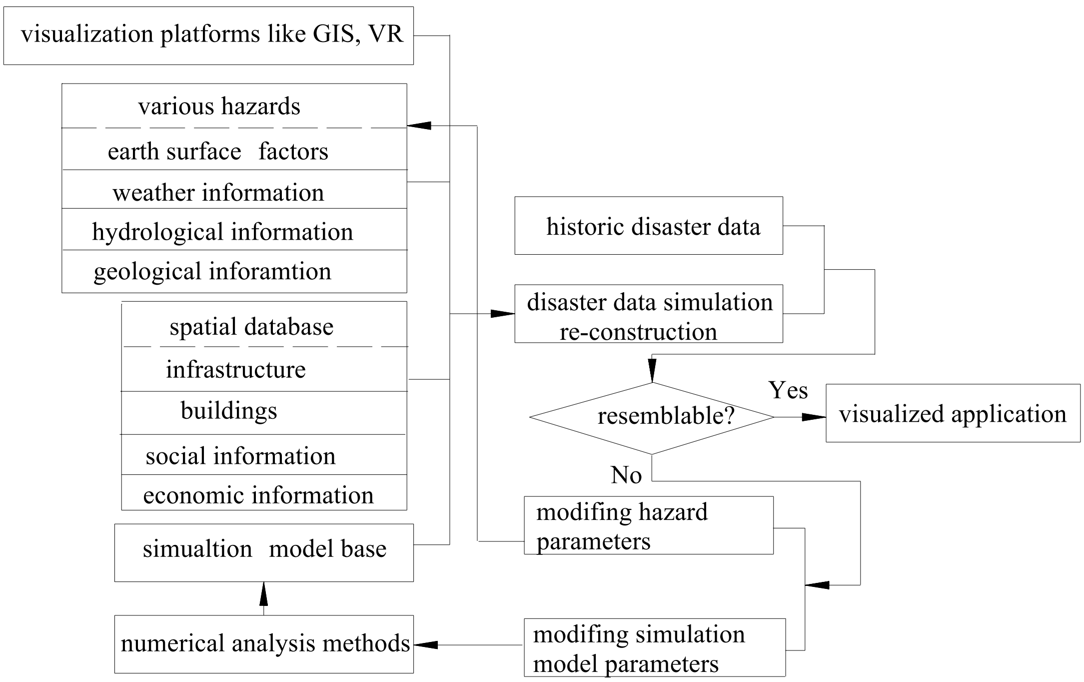


Figure 3.16. The operation flow of digital disaster simulation theory (Wang et al. 2006)

3.2.3 Terrain Component

Terrain implied in this section is a digital file that contains the elevation information of the study area. In GIS, the term digital terrain model (DTM) corresponds to the landscape. DTM is a sort of digital elevation model (DEM), which is a more general term that covers DTM and digital surface models (DSM). The difference between DTM and DSM is that DSM contains man-made objects like buildings while DTM includes only surface of the Earth. In these visualizations which are the subject of the framework, urban objects and hazard medium are visualized over the DTM.

Landscape paintings were the starting point of cartography and the related sciences. The first drawings to be considered as cartographical were found in Catal Hoyuk, now within the province of Konya, Turkey. The concept of perspective, which was the central innovational idea of the Renaissance art, also affects cartography (figure 3.17).

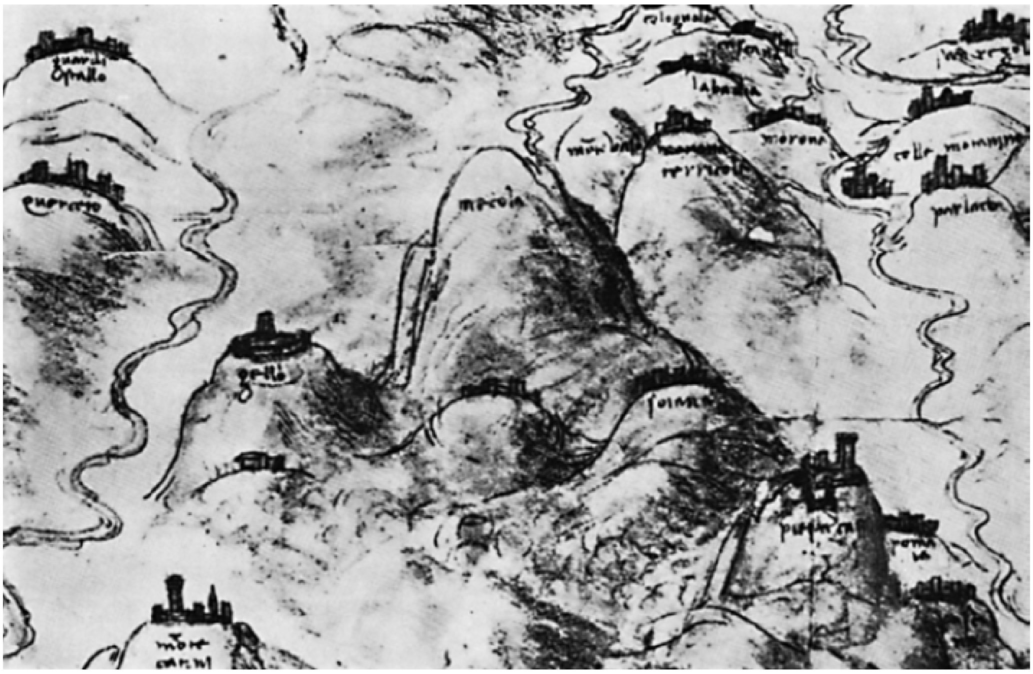


Figure 3.17. Leonardo da Vinci's maps of Tuscany (Mach and Petschek, 2007)

The first digital elevation models (DEM) were created by Miller and Laflamme, (1958). The most challenging part of DTM generation is finding information on height. Basic data sources for DTM generation are (Mach and Petschek, 2007);

- Existing geometrical data (in the vector or raster format)
- Image data from aerial photographs or satellites images
- Laser scanning output
- GPS measurement

The collection of the required data is not sufficient to create DTM visualization. The surface generation functions of the GIS software are needed to convert discrete measurements to continuous representations like Triangulated Irregular Network TIN or grid DTM. Today, most of the GIS software provides probabilistic (Kriging) or deterministic (Inverse Distance Weighting (IDW)) surface generation functions. The generated surfaces could be handled in 3D form in the visualization tools which are specially created for 3D visualization (figure 3.18).

Vector data integration is also available in these tools. The integration of the visualization components (urban objects, DTM and hazard medium) to generate a complete 3D urban visualization environment is introduced in the implementations chapter.

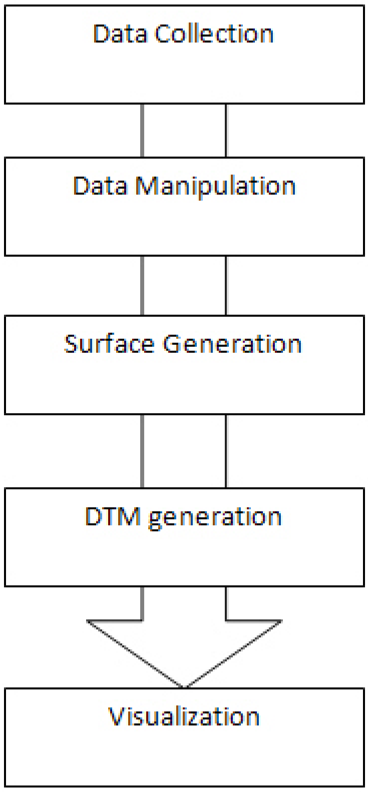


Figure 3.18. The process steps of DTM visualization (adopted from Mach and Petschek, 2007)

CHAPTER 4

OBJECT REPRESENTATION

In this chapter, the analysis of representation requirements of urban model objects, which was defined in the previous chapter, is analyzed especially for the building objects. Representation requirements demonstrate which type of object conceptualization is the most appropriate to come up with a decision tool, which has a fine communication capability for the user.

In order to find the most appropriate object representation, a definition rule is proposed. To meet the most appropriate object representation and to develop a decision rule, spatio-temporal characteristics of natural hazards and urban should be examined. After a general introduction to the spatio-temporal characteristics of natural hazards and urban is completed, the parameters for the generation of the proposed decision rule are introduced. In the second part of the chapter, the hierarchical structure of the utilization of the proposed decision rule is explained. LoD definition rule includes a hierarchical structure depending on the scale. The scale definition of the application depends on the prevalence of the natural hazard or sources that can be allocated to the intended visualization issue. On the highest scale, the entire city spot is considered as a whole. In sub-scales, the decision of object representation is generated by decision rule for urban zones (which is determined considering the urban characteristics) or for each single building object.

4.1 Background

To establish an association between natural hazards and the urban element of 3D natural hazard visualization issue, a natural hazards classification approach is required. This classification should be done considering their characteristics. The parameters of spatial and temporal characteristics play a key role in this connection. These urban and natural hazard-related spatio-temporal characteristics can give some clues about the intensity or prevalence of the natural hazard and the vulnerability of the considered urban environment. However, in this case the representation requirements of the modeling objects should be determined.

In order to establish a link between a natural hazard and a particular 3D model, two groups of criteria must be considered, namely *hazard* and *urban*. While the hazard criteria attempt to classify the hazard, urban criteria take into account the characteristics of a specific urban area.

In the literature, disasters are classified according to their cause, i.e., natural or man-made/technological (Mitroff, 1988; Haddow and Bullock, 2003; Shaluf, 2007) (figure 4.1), and natural disasters that are a subclass of disasters can be classified according to their environment, i.e., atmosphere-, hydrology-, lithosphere- and biosphere-related (figure 4.2) (Richardson, 1994; Kaplan 1996).

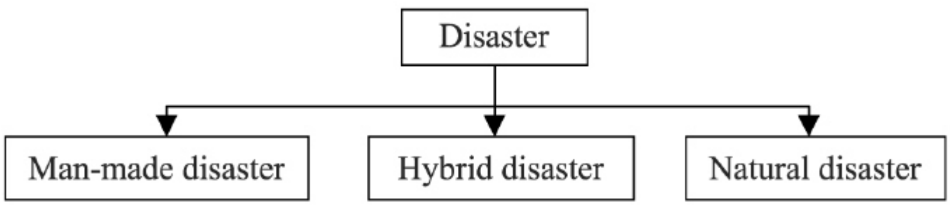


Figure 4.1. Disaster types (Shaluf 2007)

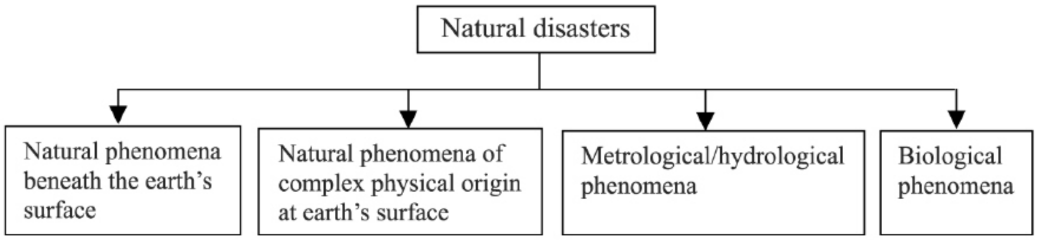


Figure 4.2. Natural disaster types (Shaluf 2007)

In general, there is no adequate scale to compare the magnitudes of different types of natural hazards. Magnitude comparison could be accomplished using scales that have been constructed taking into account the effect of the natural disaster on socio-economic and physical environment; these scales are specially devised for certain hazard types, and were developed to enable the comparison of different hazard incidents. Examples of such scales include the Modified Mercalli earthquake intensity scale (Wood and Neumann, 1931), the tsunami intensity scale (Soloviev, 1978), the volcanic eruption scale (Tsuya, 1955; Newhall and Self, 1982; Fedetov, 1985) and the landslide damage intensity scale (Alexander, 1986).

The intensity of the hazard and the extent of its spatial effect on affected areas form the basis of urban modeling studies. In the literature, no sophisticated classification method exists to compare the spatial effects of different types of disasters. Burton et al. (1993) presented six parameters for assessing the potential impact of a natural disaster. These parameters are;

Frequency reflects the time interval in which a natural disaster occurs. For example, an earthquake may occur with a lognormal frequency, while a landslide may occur seasonally.

Duration is the period of time over which a disaster continues. Hence, it may range from seconds to years. For example, earthquakes occur in relatively short periods, while certain landslide types (e.g. creeping slopes) are long-term processes.

Spatial Dispersion refers to the pattern of the distribution of a hazard over the geographic area in which the hazard may occur. This parameter ranges between small to large.

Speed of Onset is an important variable since it determines the warning time. Most extreme disaster types such as earthquakes, mudflows and flash floods give virtually no warning. Other disasters such as creeping slopes, drought and desertification act slowly over a period of days, months or years.

Areal Extent is the spatial density of the disaster on the Earth surface, e.g. the earthquake zones are limited as the tectonic plates govern them.

Temporal Spacing refers to the sequencing and seasonality of disaster events. Some disasters occur with no seasonality like volcanoes while others are seasonal in nature, such as hurricanes, tropical cyclones, and floods.

These parameters provide sufficient background to find the proper 3D spatial object representation needed for the proposed framework. Figure 4.3 presents a graphical representation of this approach. As can be seen, a hazardous event that occurs frequently, with a long duration and a fast speed of onset, over a large area causes the most pervasive effect to the urban environment. For example, urban earthquakes can be a more prevalent hazard than landslides.

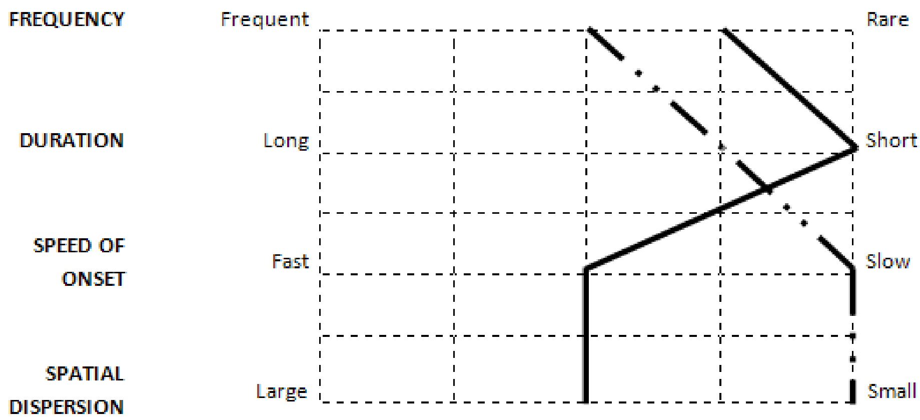


Figure 4.3. Hazard prevalence level of earthquake and landslide cases (the flat line represents an earthquake, and the dotted line represents a rapidly moving landslide), adopted from Burton et al. 1993.

4.1.1 Hazard-related Criteria

The classification given by Burton et al. (1993) is used as the starting point in the proposed decision rule. Disaster classification parameters defined by Burton et al. (1993) constitute an adequate qualitative background, but in addition to these, the association between hazard and urban elements of the desired visualization requires quantitative indicators. The index of prevalence is an index of this type, generated to come up a comparable, and most importantly, an assessable indicator. To obtain such an index, index entries must be measurable values, e.g. spatial extent measured by the area hit by a natural hazard. *Frequency, duration, speed of onset* and *spatial dispersion* parameters with indoor penetration are taken into account as they are found to be sufficient to generate a disaster prevalence index.

Burton's last parameter '*temporal spacing*' is not applicable to the framework, because the relation of temporal spacing with spatial and temporal definitions of 3D urban models can not be clearly defined.

Some natural hazards commit their fatal effects on built environment through the intrusion of hazard material into the built structure. This material can be soil, mud or rock in landslides or water in floods and tsunamis. The parameter of *Indoor penetration* is used to determine the indoor LoD. For instance, storey level indoor representation would be beneficial in a tsunami case that has relatively large spatial dispersion, so the prevalence index value is high. This means the course representation with indoor is suitable for a large area.

A classification, which constitutes the final version of the hazard-related criteria set to compare the characteristics of hazardous event, is developed and published thoroughout the course of PhD study (Kemec et al., 2010). According to this approach, five subcriteria reflecting the prevalence of the disaster are defined as follows:

- The *Frequency* reflects the time interval between the occurrences of two natural disasters. In this criterion, spatial comparison is carried out with a relative frequency distribution approach.
- The *Duration* is the period of time over which the disaster continues. Hence, it may range from seconds to years. For example, earthquakes occur in relatively short periods, while certain landslides types (e.g. creeping slopes) are long-term processes.
- The *Speed of Onset* is the length of time between the first emergence of the hazard event and its summit. It is an important variable since it defines the warning time. Extreme events such as earthquakes, mudflows and flash floods, volcanic eraptions are sudden onset disasters. Other disasters, such as drought and desertification,creeping landslides act slowly over a period of days, months, or years.
- The *Spatial Dispersion* refers to the spatial distribution pattern of natural hazard occurrences. Depending on the scale, spatial analysis entity could be a point, a line, or a polygon. That is, the pattern of a landslide could be analyzed by a point in a small-scale occurrence or a polygon in a large-scale case.

- The *Indoor Penetration* refers to intrusion of hazard material (e.g., soil, mud, or rock in case of landslides, or water in cases of floods and tsunamis) into built structures. This parameter addresses the question of whether and to what extent indoor LoD is needed in the visualisation (note that the amount of detail needed may differ from case to case).

4.1.2 Urban-related Criteria

In the 3D object representation decision rule, three parameters are introduced as the urban-related criteria, the second element of the visualization issue, in addition to the hazard-related criteria.

Urban systems are complex, comprising physical and socio-economic subsystems. Moreover, an urban texture settled on a highly vulnerable, small area with a high population density makes these complex structures difficult to understand, hence there is a need for a more detailed approach. Urban areas can be characterised by three subcriteria (Sudhira et al., 2004; Kemec et al., 2009). Two of them are physical parameters (natural and manmade), and the other one is a social parameter:

- The *Disaster Susceptibility* is the spatial density of the disaster, and it is defined by the physical susceptibility the urban land. The parameters, which are taken into account to achieve this physical susceptibility, vary from hazard to hazard. For example, in small-scale earthquake zones they are limited as tectonic plates govern them. On the other hand, on large-scale alluvium ground is more vulnerable than rock one.

- The *Urban Areal Extent* is related to the size of the urban area. An area with a population above 5000 and without an adjacent settlement within a 3-km buffer zone is assumed to be an urban area (Balk and Yetman 2004).

- The *Population Density* is defined as the number of people residing within one hectare. Urban textures with a high population density need more detailed visualization approaches than ones with a low population density.

4.2 Proposed Decision Rule

The proposed decision rule is used to establish a link between these two classification systems (hazard and urban). The decision rule is based on multi-attribute decision rule described by Malczewski (1999). The aim of Multi-Attribute Decision Analysis (MADA) is to choose the most suitable alternative using decision criteria and attributes.

The decision is made by applying four main MADA attribute combination rules (Malczewski, 2006): *weighted summation*, *ideal/reference/point*, *outranking methods* and *analytic hierarchy process* (AHP). The first rule assumes that all attributes have a linear relation with the decision. This linear relation implies that the decision can be made by adding the standardized values of the attributes. The weights are often obtained simply by asking the decision-maker to assign numerical values directly to each criterion or sub-criterion according to a pre-defined maximum and minimum quantisation scale (i.e., 0-1 or 0-100). In the second rule, there is an assumed theoretical ideal solution, and the set of possible alternatives is ordered according to their closeness to this hypothetical ideal solution. The closest alternative to this point is chosen as the best alternative (Malczewski, 1999). The outranking method deals with situations in which some attributes have incomplete values. This method provides only an indication for the ranking of alternatives (Malczewski, 2006).

The AHP methods work based on three principles: *decomposition*, *comparative judgment* and *synthesis of priorities*. Decomposition requires that the criteria must be grouped accordingly, while comparative judgment requires careful consideration of the place in the diagram, and finally the synthesis of priorities refers to the consideration of the branches in the diagram. These principles are applied to construct the hierarchy (Malczewski, 1999). The AHP method is regarded as the most appropriate one for the decision rule of the proposed framework since the weights of the attributes for the situations cannot be considered equal.

The decision rule parameters of 3D urban model object representation definitions are used to achieve the so-called *prevalence index* of different hazard types and for different urban areas. The hazard-related criteria part of the index is obtained from the parameters of *frequency*, *duration*, *speed of onset* and *spatial dispersion*.

Each parameter is normalised to obtain a value on a scale from one to five. Each of four parameters that form the shape of the prevalence function is related to a hazard type. The cumulative evaluation of these parameters constitutes the hazard-related part of the prevalence approach, which aims to relate the hazard type and the spatial characteristics of the desired 3D urban model.

Disaster Susceptibility, *Urban Areal Extent* and the *Population Density* parameters constitutes the urban-related criteria of the decision rule. They are used for the target city to evaluate the LoD level of the desired 3D urban model. If a hazard occurs in an urban area which is settled on a highly susceptible terrain and which has a high areal extent and low population density, it causes pervasive effect to this environment.

The AHP approach is applied to build relations between different criteria and their attributes in the rule-based diagram (figure 4.4). The criteria examined in this study are the evaluation principles that are applied in the decision-making process. Some criteria may also have subcriteria. All of the criteria (subcriteria) have measurable attributes, which take on well-defined values. The values are used ultimately to compare different alternatives.

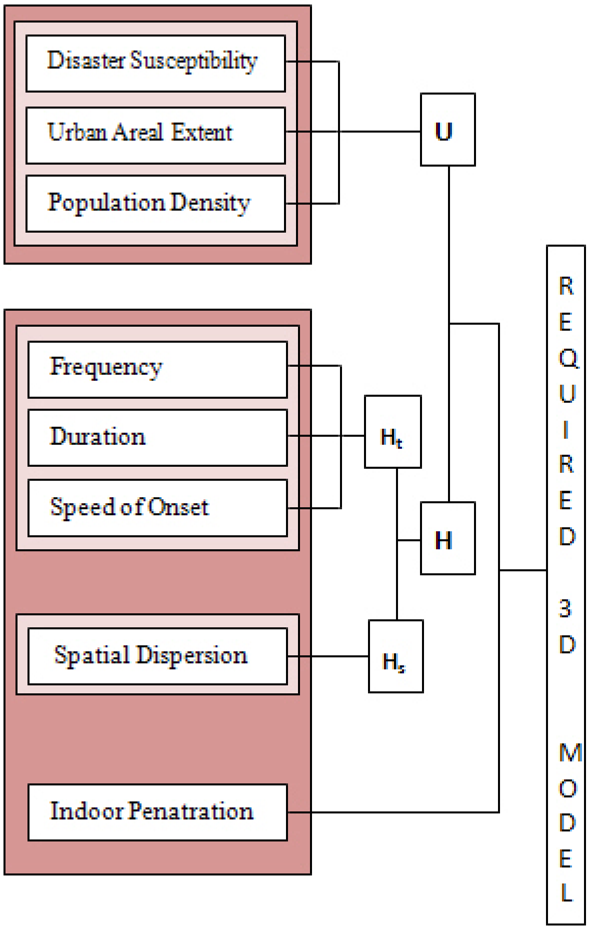


Figure 4.4. Rule-based decision diagram

According to the decomposition principle, the relation of the criteria to the decision is organised in a decision diagram (figure 4.4). The decision diagram consists of three levels, at which the criteria, subcriteria and attributes are placed. The weights of the attributes are derived from the location of the attribute in the diagram, where branches at the same level have the same weight. For example, the hazard criteria *H* and the urban criteria *U* both have weights of 50%.

Decision diagram assists stakeholders by making a decision to find the required 3D model. As it is mentioned earlier, there are two main categories of criteria that influence this decision: *hazard* and *urban*. Therefore, these are found at the first level below the root of the diagram. In the second level of the decision, the two subcriteria of the hazard are placed: one subcriterion relates to the spatial characteristics H_s and the other relates to the temporal characteristics of the hazard H_t. The third level contains the attributes of the subcriteria. While *Spatial Dispersion* represents the spatial characteristics of hazard (H_s), the temporal characteristics of hazard, H_t, are given by the attributes of *Speed of Onset*, *Duration* and *Frequency*. The *Urban Areal Extent, Disaster Susceptibility* and *Population Density* are the attributes of the urban-related criterion *U* (figure 4.4). The urban criterion does not have subcriteria. Using this approach, all of the characteristics as specified in Section 2 are organized into a decision diagram.

Following the AHP approach, the weights of the attributes are derived as follows; Urban- and hazard-related criteria have the same effect on the decision, so they have equal weights. Similarly, each temporal and spatial hazard subcriterion has a 50% weight. The attributes of each of the subcriteria also have equal weights. As the urban criterion does not have subcriteria, its attributes are given higher weights compared to the attributes of the hazard criteria. Thus, three urban-related attributes have weights of 16,7%, while the temporal and spatial hazard attributes have weights of 8.3% and 25%, respectively. The synthesis of all these weights constitutes the decision priorities. However, the assignment of weights can be modified based on the judgement of decision makers.

The decision diagram is further used to derive a mathematical expression to compute the output of the 3D model and, more specifically, the LoD. A function *prevalence index* (I_p), which together with the *indoor penetration i,* defines the LoD of the 3D model, is defined.

The function I_p is defined as the product of the hazard and urban criteria. The prevalence function represents the risk of hazard. In general, the risk in a given area is defined in the literature as the product of the hazard potential and its consequences (Duzgun and Lacasse, 2005; Basta et al., 2007), or the product of hazard, elements at risk and vulnerability. The elements at risk in this case are given by the urban criteria. Therefore:

$$I_p = (H \times U), \qquad (1)$$

where I_p is the *prevalence index, H* is the value associated with the *hazard-related criteria* and *U* is the value associated with the *urban-related criteria*. *H* can be subdivided into contributions from *temporal* and *spatial* subcriteria:

$$H = H_t + H_s \qquad (2)$$

where, H_t is the value associated with hazard *temporal subcriterion* and H_s the value associated with hazard *spatial subcriterion.* The temporal subcriterion has three attributes: *speed of onset*, *duration* and *frequency*:

$$H_t = ((f + d + s_o) / 3) \qquad (3)$$

where *f* is the *frequency*, *d,* the *duration* and s_o the *speed of onset*. The spatial subcriterion has one attribute, s*patial dispersion,* is the s_d simply equal to H_s.

The urban criterion does not contain subcriteria, but has three attributes, as specified earlier: *disaster susceptibility, urban areal extent,* and *population density*; therefore, it can be represented as:

$$U = (d_s + u_{ae} + p) / 3) \qquad (4)$$

where, d_s is the *disaster susceptibility,* u_{ae} is the *urban areal extent* and *p*, the *population density*. Substituting (2), (3) and (4) into (1) results in the extended representation of I_p with all of the attributes:

$$I_p = [(d_s + u_{ae} + p) / 3) \times (((s_o + d + f) / 3) + s_d) / 2)] \qquad (5)$$

In the decision rule, I_p can vary between 0 and 100. Figure 4.5 represents the relation between I_p and D.

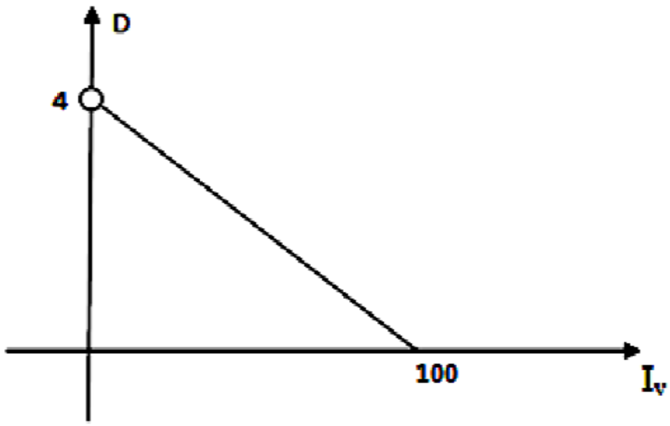


Figure 4.5. I_p value and the level of detail relation

$$f(D) = \begin{cases} \text{If} \quad I_p > 0 \quad f(D) \\ \text{If} \quad I_p = 0 \quad \text{no need for modeling} \end{cases} \tag{6}$$

For $I_p = 0$, the function f(D) gives the most detailed result. However, this case should be interpreted as one in which modeling is not required; hence the partial function of (6) eliminates this case. The *normalised intensity value* I_{pnorm} is defined as:

$$I_{pnorm} = ((I_p - I_{pmax}) / (I_{pmin} - I_{pmax})) \times 4)_{round} \tag{7}$$

where I_{pmax} is the maximum prevalence value and I_{pmin} is the minimum prevalence value. Attribute values are rated in the prevalence direction, which means that a high I_p indicates a pervasive situation that requires low spatial detail and a low I_p indicates an intensive situation requiring high spatial detail. An inverse linear transformation is applied with four levels of quantisation, because there are five different alternatives with respect to LoD0 to LoD4. The obtained result is rounded because the LoD must be an integer (0 to 4). Finally, the required LoD, denoted with *D*, can be computed as follows:

$$D = I_{pnorm} + i/2 \quad (8)$$

The indoor penetration attribute *i* is a Boolean value that indicates whether there is indoor penetration (1) or not (0). Thus, an integer value of *D* implies that there is no need for indoor modeling, while the opposite is true otherwise. For example, in the case that D equals 2.5, the required 3D model will have an outdoor LoD of 2 (as defined in CityGML) and an indoor LoD that is compatible with the outdoor LoD for a building, which means the indoor LoD of floor compartment level is needed.

4.3 Proposed Multi-Scale Conceptual Model

The proposed decision rule for the representation definitions of the model objects at the phase of the analysis of representation requirements in the framework is a generic rule and applicable to the cities, city zones or directly to the building object itself. This is because the spatial dispersion of different natural hazards varies. The effect of the earthquake may be at of multiple cities. On the contrary, a landslide may hit only one building or a group of buildings. Therefore, the application of the decision rule needs a multi-scale conceptual model to evaluate all the different natural hazard conditions.

In this context, the research into the definition of the city zone matches the small-scale geography concept discussions. In the urban geography literature, there are two main directions to explain the city zones, also called, urban segregation. Actually, city zone and partition summarize these two approaches. According to the first approach, city zones are purely the result of public requests (Rossi, 1955; Speare et al., 1975). Partition on the other hand, underpins institutions, and public intervention, which causes an urban segregation (Pahl, 1975; Galster et al., 1987).

Aside from these traditional enlightenments, current understandings on the subject integrate with the cities in developing countries. The cities in the developed countries have a functional partition; the homogeneous parts constitute the whole. However, the situation is quite different in the developing countries. In addition to the physical reasons which led to urban partitioning, the subject has social origins.

These could be associated with the concepts of globalization and neo-liberalization. Eventually, this kind of partitioning resulted in the formation of urban zones with heterogeneous structure (Evren, 2007).

Detailed approaches to dealing with this heterogeneous structure are needed to generate applicable disaster management strategies. To this end, the framework proposes a multi-scale 3D urban model evaluation approach. According to this approach, a three-level evaluation is defined. At the top level the evaluation of urban model object representation is executed on the whole city scale by using the proposed decision rule. If necessary, more detailed studies are conducted on the urban zone scale at the second level. Again if necessary, the most detailed decision evaluation is carried out at the third level, in which the evaluation is executed for each building object (figure 4.6).

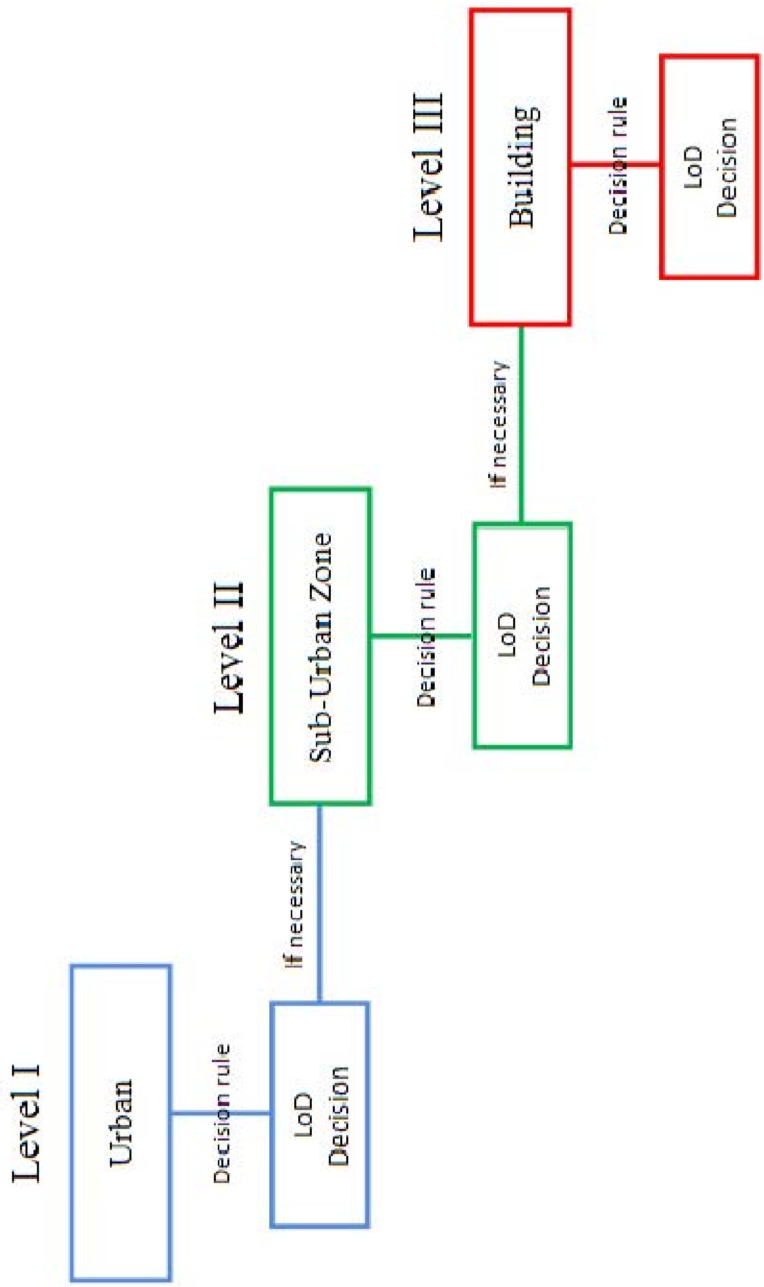


Figure 4.6. Three-level urban object evaluation approach

There is no problem about evaluation at the top and the lowest levels but an urban zonation is needed to find the Sub-urban zones for the evaluation at the second level. As it was mentioned in the previous parts, this issue is more complicated in the developing countries when compared to the developed ones. The US Census Bureau's geographic hierarchy can be given as an example of a solution in a developed country.

The US Census Bureau uses legal/administrative and statistical geographic entities to provide a geographic hierarchy (figure 4.7). This hierarchy starts from the nation level and ends with blocks (Bureau of the Census, U.S., 1994). Census Block is the smallest entity, bounded on all sides by visible and non-visible map features.

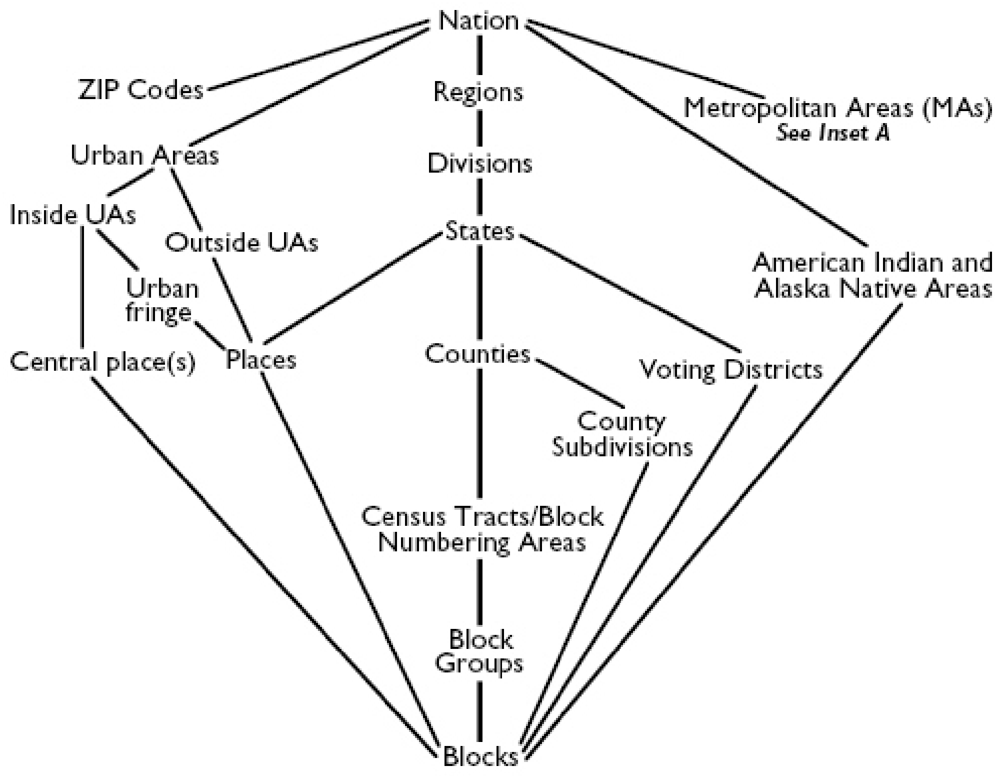


Figure 4.7. Geographic Hierarchy for the 1990 Decennial Census (Bureau of the Census, U.S., 1994)

In Turkey, there are no such geographic hierarchy approaches. The smallest geographic entity, neighbourhood, is an administrative definition. Most importantly, a neighborhood does not have homogeneous social and physical characteristics. In the dissertation, an urban zoning approach is suggested to find homogeneous urban zones and to come up with a representation definition decision of these zones at the second level. The proposed approach uses building pattern physical characteristics attributes to find the desired zone definitions, because the physical characteristics of a building texture is the key for 3D representation.

4.3.1 Sub-urban Level Zoning by Building Spatial Pattern

The recognition of building pattern and the definition of zones with similar building pattern are new in cartography and urban modeling. In this study, two different approaches are tested to find the resultant maps and their conformity for the needed urban zones in the framework. These approaches are;

- Self-organizing Maps (SOM)
- Image segmentation

At the beginning of the application of the zonation approaches, some data conversion operations are required in the data preparation stage. There are certain reasons for this requirement. First, in both zonation approaches, while some of the attributes used are measured by using polygon data model functions (e.g. Polygon-based measurements, area and perimeter), some are measured by using point data model functions (e.g. Point-based measurements, density and distance related measurements). Another important reason is that the resultant of these applications should be in a zone form that does not have spaces in between.

The first step of these conversions is given in figure 4.8 and figure 4.9, where a point data layer is created by converting the building polygons to the point data (figure 4.8). Then, point to polygon conversion (figure 4.9) is applied via voronoi/thiessen polygons to come up with the desired polygon based zone outputs.

The created voronoi layer, which contains the computed spatial attributes, constitutes the main input of the tested zonation approaches.

Figure 4.8. Polygon to point conversion

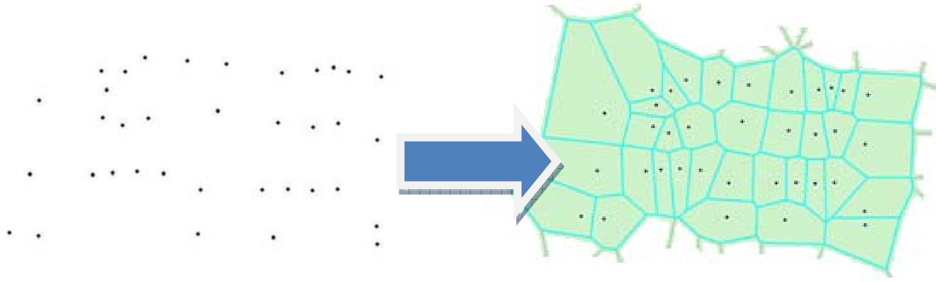


Figure 4.9. Point to polygon (voronoi/thiessen) conversion

In the literature, these zonation approaches could be appraised in the multivariate cluster analysis. In spite of the variety of the application areas and its convenience, cluster analysis is new technique. The definition of the cluster analysis could be done as an analysis, which looks for the information organization between the introduced attributes to obtain homogeneous zones or clusters. Spatial clustering is the task of grouping the objects of a database into meaningful subclasses (Azimi and Delavar, 2007). The difference of spatial clustering from traditional clustering algorithms is that spatial information is taken into account as a component in the spatial clustering methods.

Apart from the positional information of the input entities, the employed approaches are applied by using three different attribute groups. These attribute groups characterize three different aspects of the studied urban pattern, which are building geometry, density with derived spatial attributes, and density with kernel density function. Attribute groups with contained attributes are;

- Building geometry;
    - The perimeter of the polygon building object
    - The area of the polygon building object

- Building density;
    - Distance from the nearest building
    - The number of neighbors within the distance of 100m
    - The area of the voronoi/thiessen polygon

- Kernel density raster is created by using the kernel function of ArcGIS software. Moreover, the raster result of the function is used to generate building weight attribute, which is used as a non-spatial component.

In addition to these three zonation alternatives, a fourth zoning alternative is configured by using the districting module of ArcGIS software. In this alternative, expert opinion via visual interpretation is performed by using the same software tool. Figure 4.10 represents the visual interpretation environment created by voronoi polygons, which are formed by using point entities created at the point of building object centres.

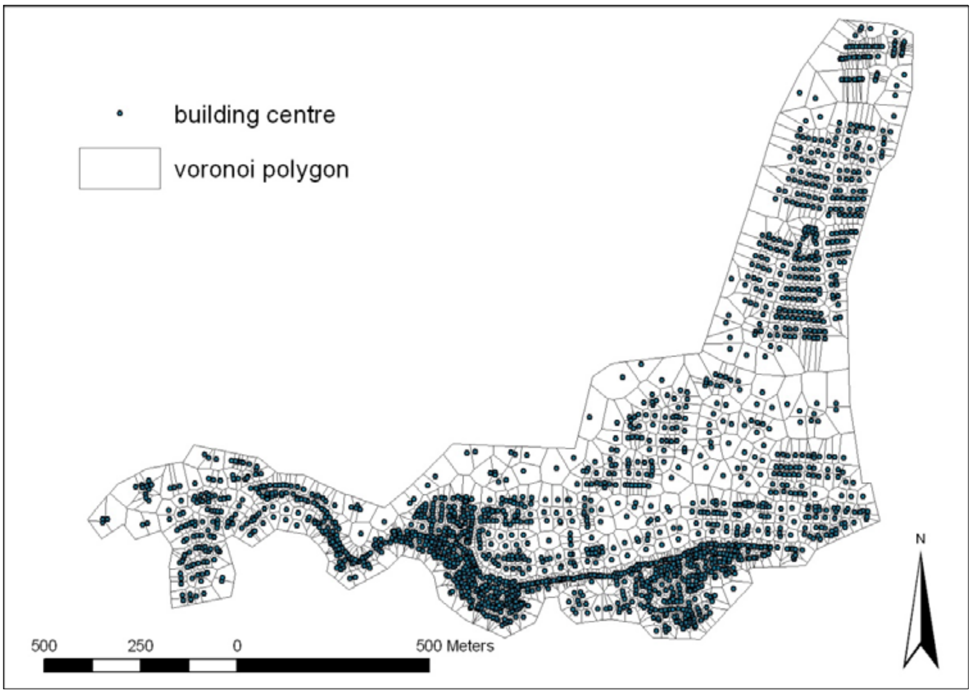


Figure 4.10. Building centre points and voronoi polygons produced by these points

The methods tested in the study for Sub-urban zonation, that is, clustering, are used to automate the zonation process. In an urban environment, the formation of building texture is effected from social, physical and economical factors, so that even the clustering algorithms can automate the process of small statistical area (SSA) generation, and replacement with manual approaches based on expert opinion seems difficult. Consequently, the result of the zonation based on expert opinion (figure 4.11) is used as a reference zonation to assess the results of two tested zonation methods for three different approaches.

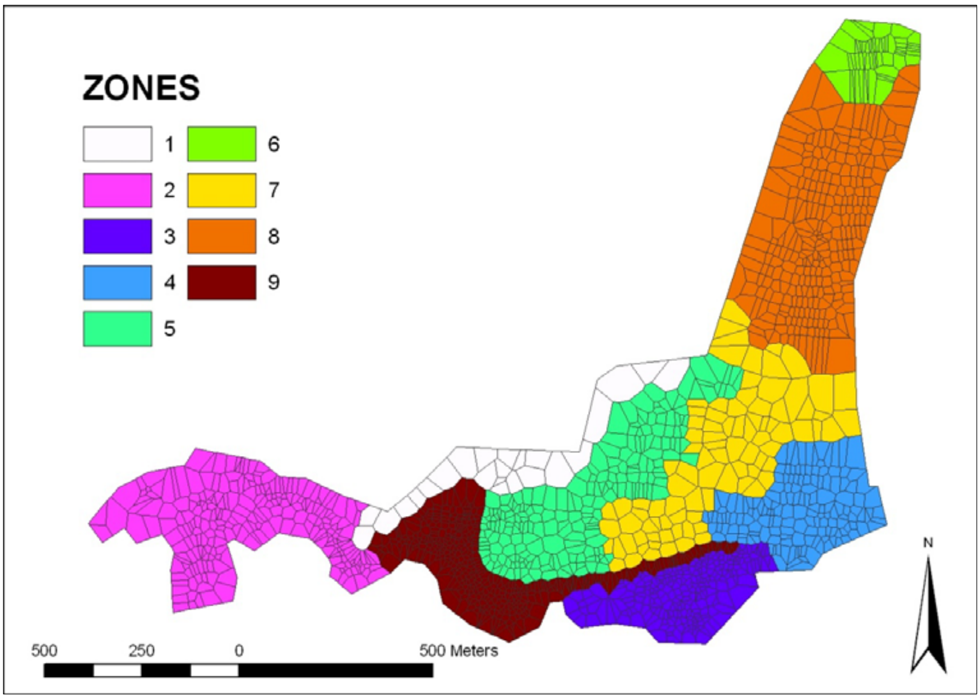


Figure 4.11. The result of the zonation based on expert opinion, used to assess clustering results.

4.3.1.1 Self-organizing Maps (SOM)

Determination of small area geography in the form of sub-neighborhood zones is particularly important in all types of urban planning and modeling studies, but it is difficult due to the high dimensionality of the spatial pattern data. The SOM algorithm is a robust technique to deal with this problem. U-matrix and the component plane representation have been utilized to determine the zones in building spatial pattern.

Kohonen (1995) introduced the SOM algorithm for the first time for basic information processing of cortical cells in human brain. The SOM is an artificial neural network method employed to map multidimensional data on a space with lesser dimensionality. It can be used to dig out information in complex data such as clustering. The SOM is mostly acknowledged as being a useful tool for the extraction of patterns and the creation of abstractions where the other clustering methods could be limited because underlying relationships are not clear or the number of classes of interest is not obvious (Koua and Kraak, 2005).

Blake and Openshaw (1995) summarized the advantages and disadvantages of the SOM algorithm. The mentioned advantages of the SOM method are;

- Use of raw data
- The self-organising nature of the SOM
- The incorporation of data uncertainty into the classification
- Simplicity in terms of coding
- Enabling prior knowledge into the classification process
- Rich content of the results
- Reduction in the importance of knowing cluster number precisely
- Easy interpretation of cluster
- Non-linear nature

The shotcomings of the method are;

- Extensive computer run time for large data sets
- Entirely subjective design aspects
- The current absence of experience in interpreting the results

Skupin and Hagelman (2005) combined the SOM method with the integrated handling of 2D visualization and attribute information provided by GIS. Besides, Fincke et al. (2008) emphasized the importance of the u-matrixes to analyze the SOM results, as u-matrixes allow the clustering of the available data.

The software package employed for the SOM for the development of sub-neighborhood clusters is GeoSOM suite v2.01 on MatLab. In the GeoSOM software package, spatial information can be introduced in the SOM process. After three traditional SOM applications with non-spatial components (in this case these are area, perimeter, or density measurements), the hierarchical SOM and GeoSOM tools could be usable (figure 4.12). Spatial information using the GeoSOM and hierarchical SOM tools can be calculated from the input geographic layer (in this case building voronoi data) or this information can be entered from the tabular data.

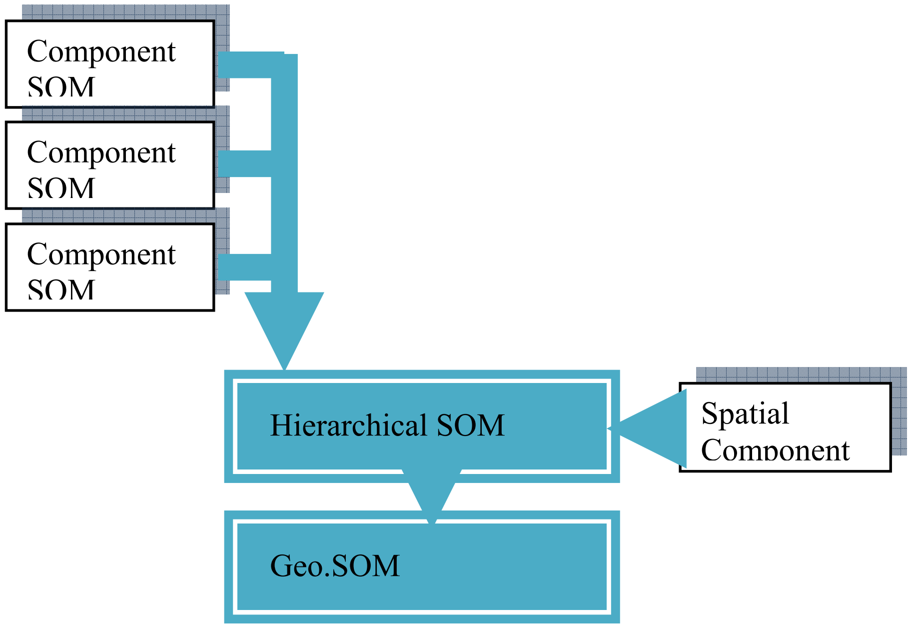


Figure 4.12. GeoSOM suite v.201 on MatLab process flow

The results of building geometry attributes' (perimeter and area) SOM cluster (map initialization is done with 9 classes) and the zonation result obtained at the end of the GeoSOM method, which is based on the building geometry approach, are given in figures 4.13. - 4.15.

- Building Perimeter (figure 4.13)

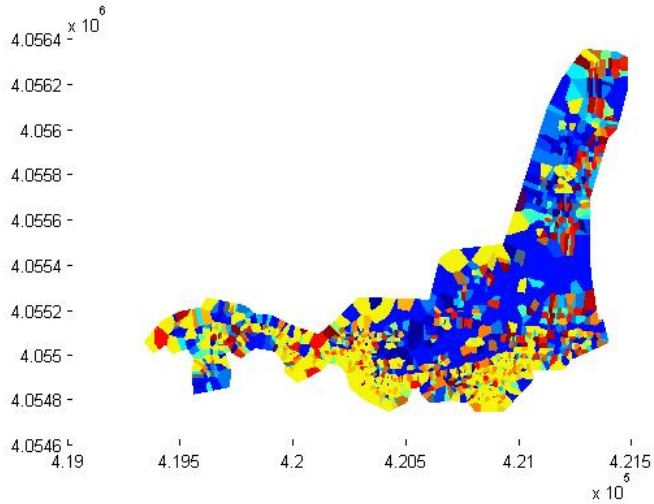


Figure 4.13. Building Perimeter attribute SOM cluster result

- Building Area (figure 4.14)

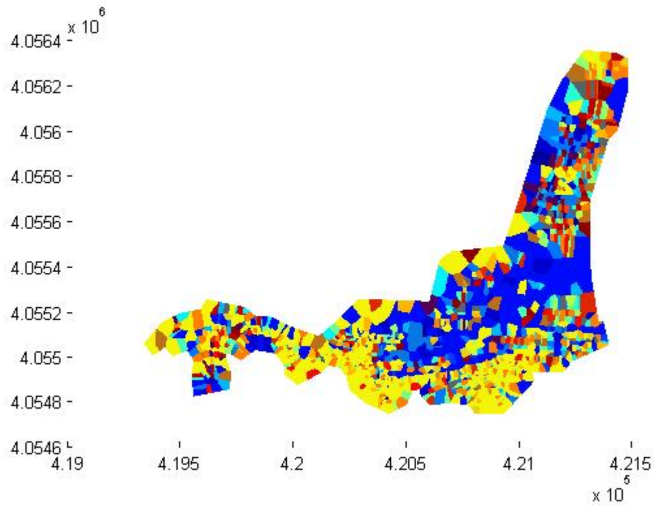


Figure 4.14. Building Area attribute SOM cluster result

- Building geometry approach GeoSOM result (figure 4.15)

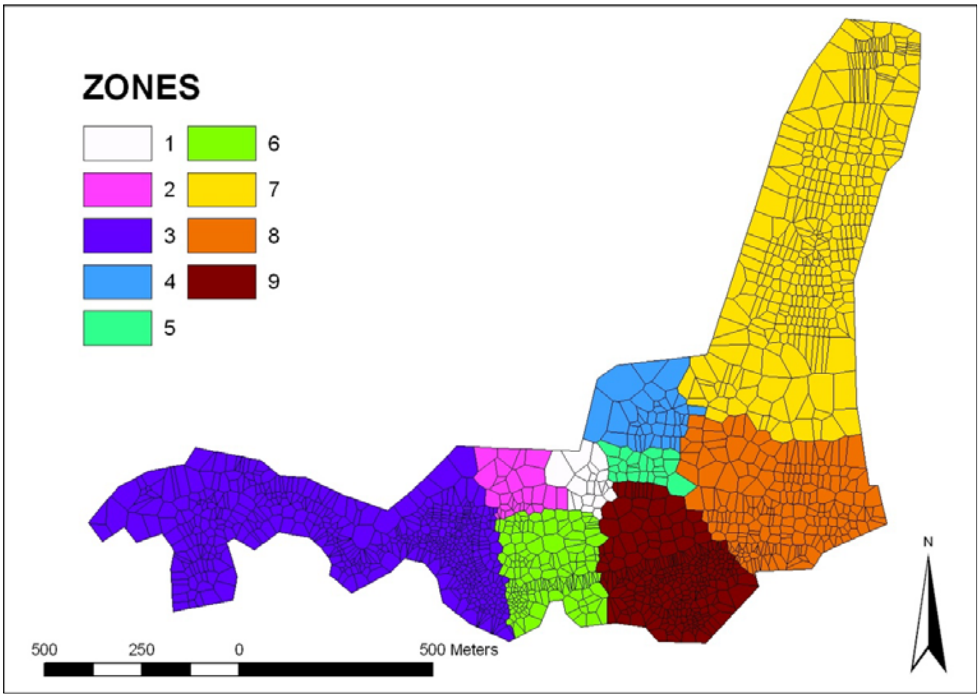


Figure 4.15. GeoSOM resultant zonation based on building geometry

The results of the SOM cluster (map initialization is again done with 9 classes) of building density attributes (Distance from the nearest building, the Number of neighbors within the distance of 100m, and the Area of the voronoi/thiessen polygon), and the zonation result obtained at the end of the GeoSOM method, which is based on the building density approach, are given in figures 4.16. - 4.19.

- Distance from the nearest building (figure 4.16)

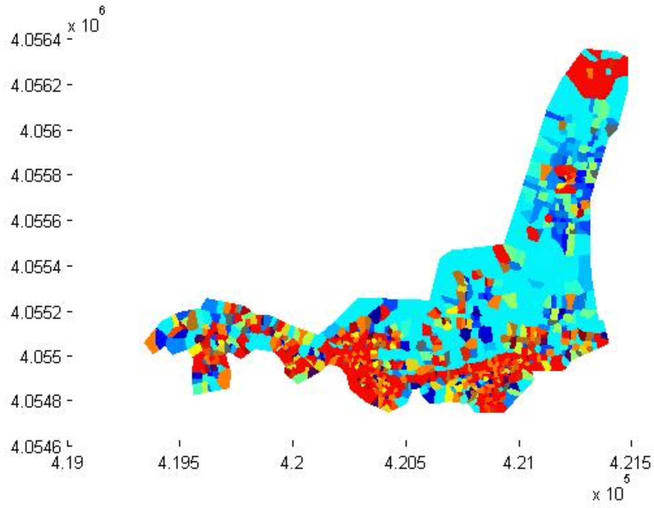


Figure 4.16. Distance from the nearest building attribute SOM cluster result

- Number of neighbors within the distance of 100m (figure 4.17)

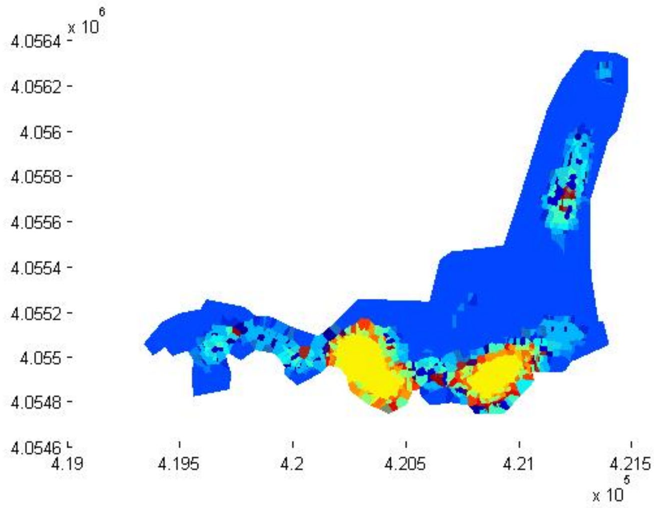


Figure 4.17. Numbers of neighbors within the distance of 100 m attribute SOM cluster result

- Area of the voronoi/thiessen polygon (figure 4.18)

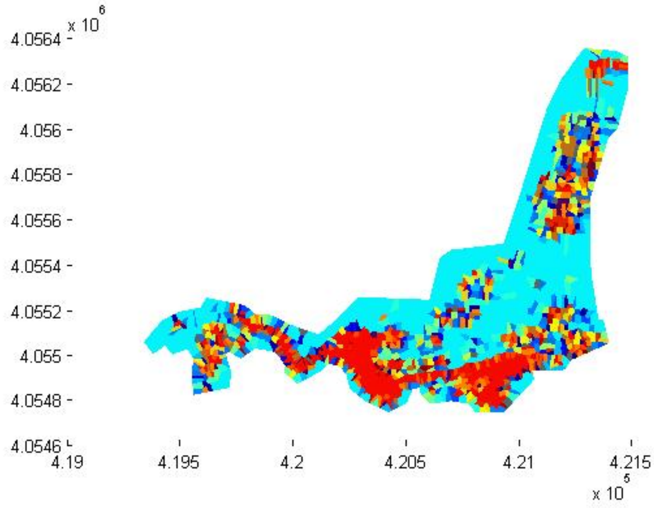


Figure 4.18. The areas of the voronoi/thiessen polygon attribute SOM cluster result

- Building geometry GeoSOM result (figure 4.19)

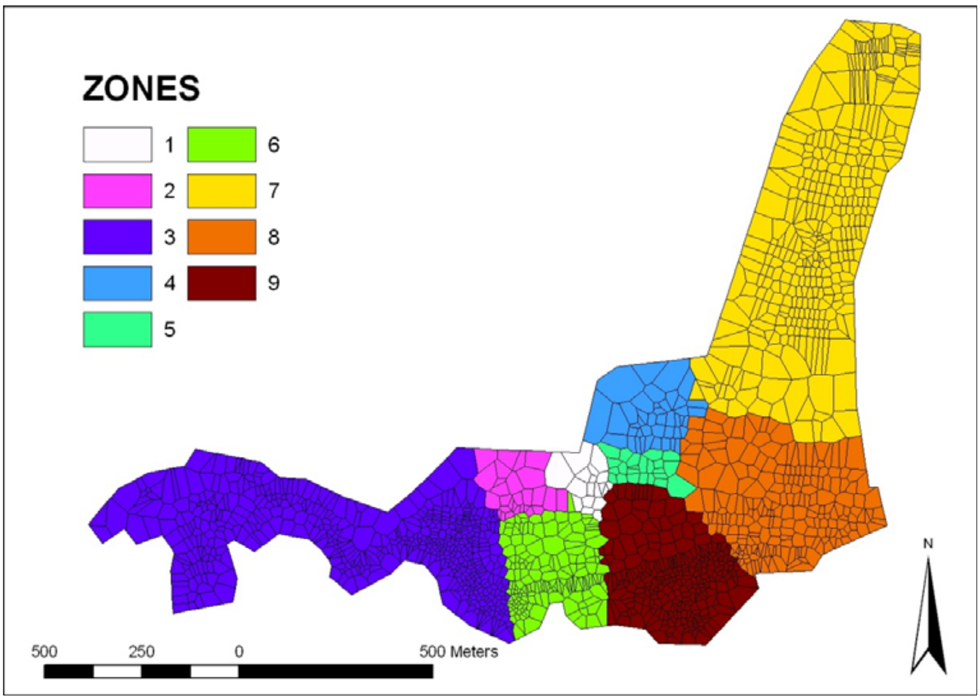


Figure 4.19. GeoSOM resultant zonation based on building density

The result of the SOM cluster (map initialization is again done with 9 classes) of the Kernel density attribute and the zonation result obtained at the end of the GeoSOM method, which is based on the kernel density approach, are given in figures 4.20. and figure 4.21.

- Kernel Density (figure 4.20)

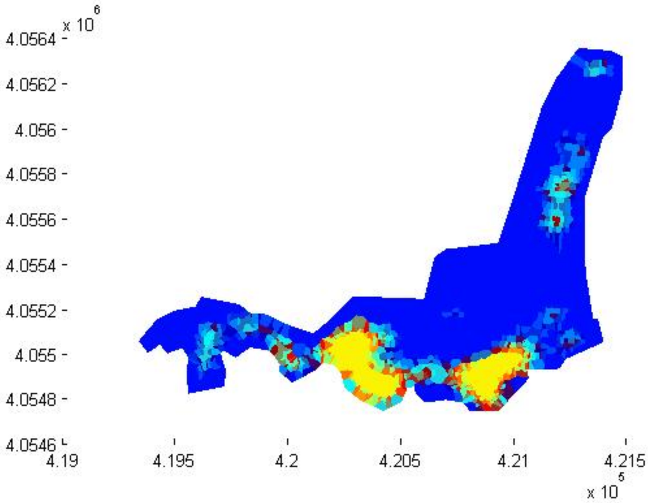


Figure 4.20. Kernel Density attributes's SOM cluster result

- Kernel Density GeoSOM result (figure 4.21)

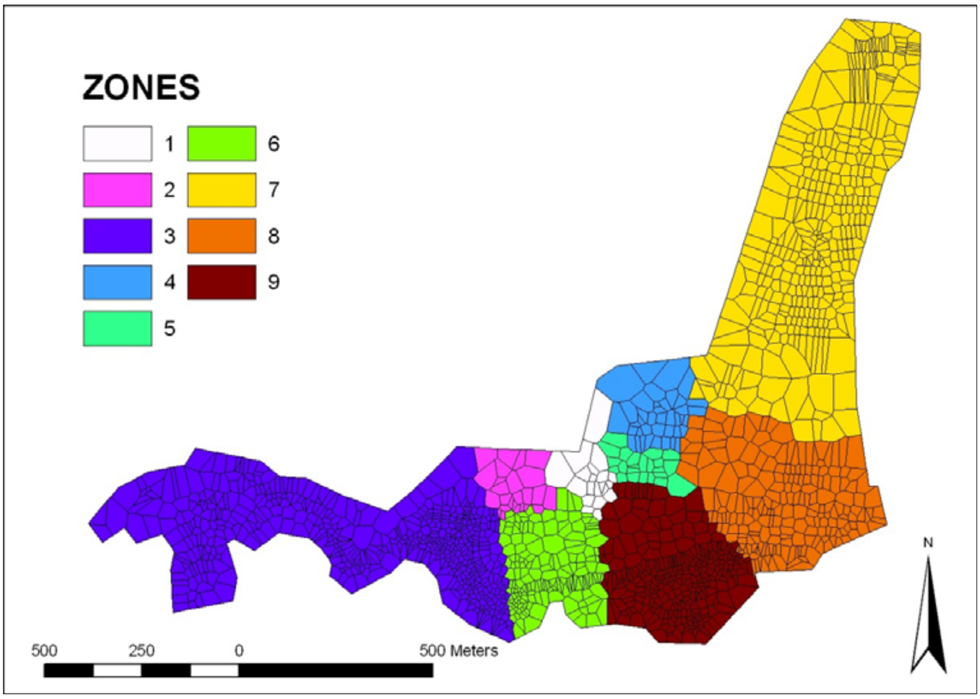


Figure 4.21. GeoSOM resultant zonation based on kernel density

Although these results give some negative tips to choose the SOM method, the GeoSOM zonation result of an integrated assessment (figure 4.22) of three approaches is generated by combining these three zonations results in order to compare them with the results of the other clustering method (mean shift).

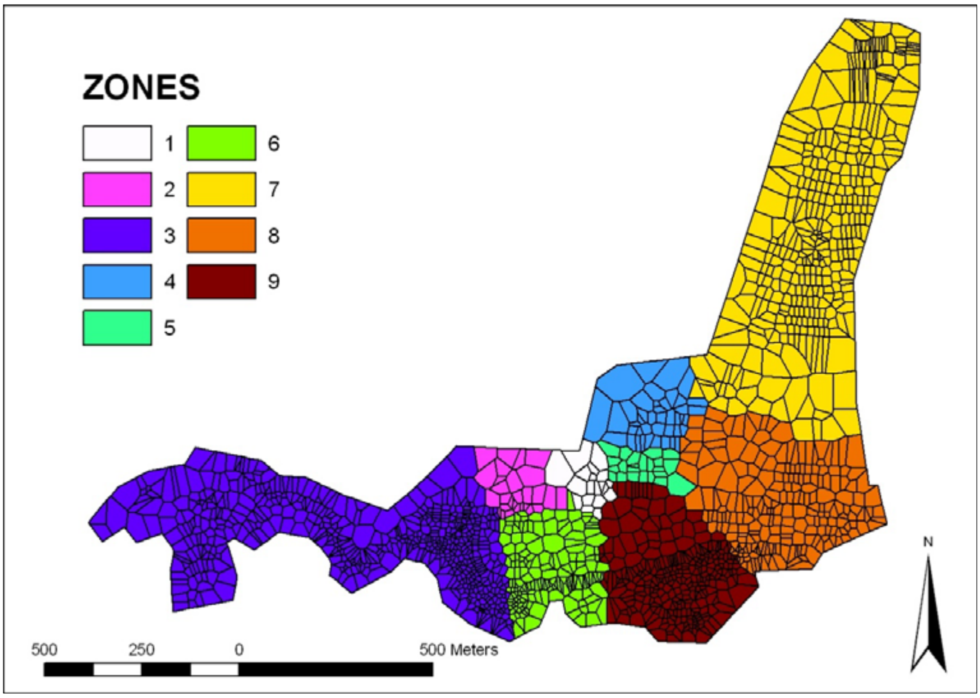


Figure 4.22. The combination of three different SOM alternative zonation results

4.3.1.2 Image segmentation

Defining urban zones by using image segmentation is another method that is commonly utilized. It uses the mean shift image segmentation alghorithim coded in (Comanicu and Meer, 2002) Edge Detection and Image Segmentation (EDISON) System software.

Unlike the SOM method, as the name implies, image segmentation is an image-based method. This method uses raster-based inputs to find the segments of homogenous zones. The situated segments are used as cluster definitions and the compliance of image segmentation approach is compared with the other method tested.

The mean shift segmentation is a non-parametric clustering procedure. In contrast to other approaches like K-means, there are neither distribution assumptions nor the number of clusters. Mean shift procedure has three main iteration steps (Derpanis, 2005); at the first step, mean shift vector is computed, and then the computed vector is translated to the density estimation window. At the last step, the steps one and two are repeated iteratively until there is no window centre shift (figure 4.23).

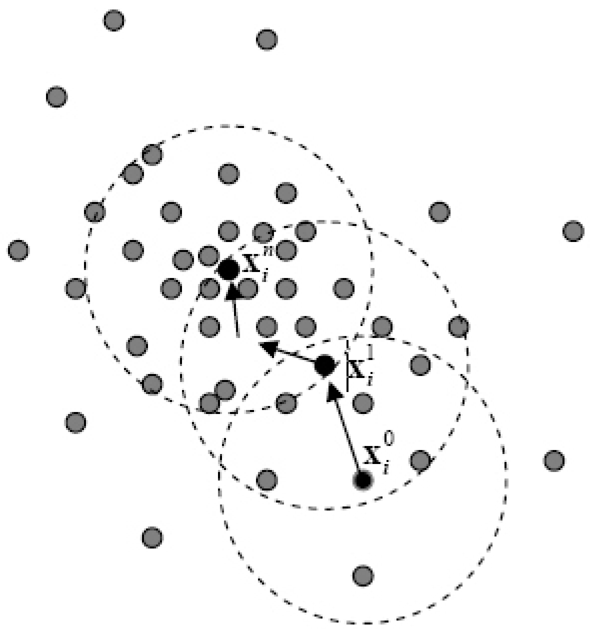


Figure 4.23. Mean shift procedure. The dotted circles denote the density estimation windows and the shaded and black dots denote the input data points and successive window centres, respectively (Derpanis, 2005).

Similar to the SOM method, the values of density, geometry, and kernel density are measured by using related attributes. To create the needed image inputs, thematic maps of building density index, building geometry index and an index from the result of the kernel density function with seven classes are generated. Building Geometry index is generated by using the attributes of "Perimeter of the polygon building object" and "Area of the polygon building object". In addition, Building Density index is generated by using the attributes of "Distance from the nearest building", "Number of neighbors within the distance of 100m" and "Area of the voronoi/thiessen polygon". In the last alternative, the index of the Kernel density value, created by using the kernel function of ArcGIS software, constitutes the weights of the voronoi polygons.

A series of conversion processes is executed at the data preparation and post-process stages. The generated vector thematic maps are converted into the raster format; at this stage, a background colour other than white is chosen to improve the contrast, so that the borderline discrimination is easily performed (figure 4.24).

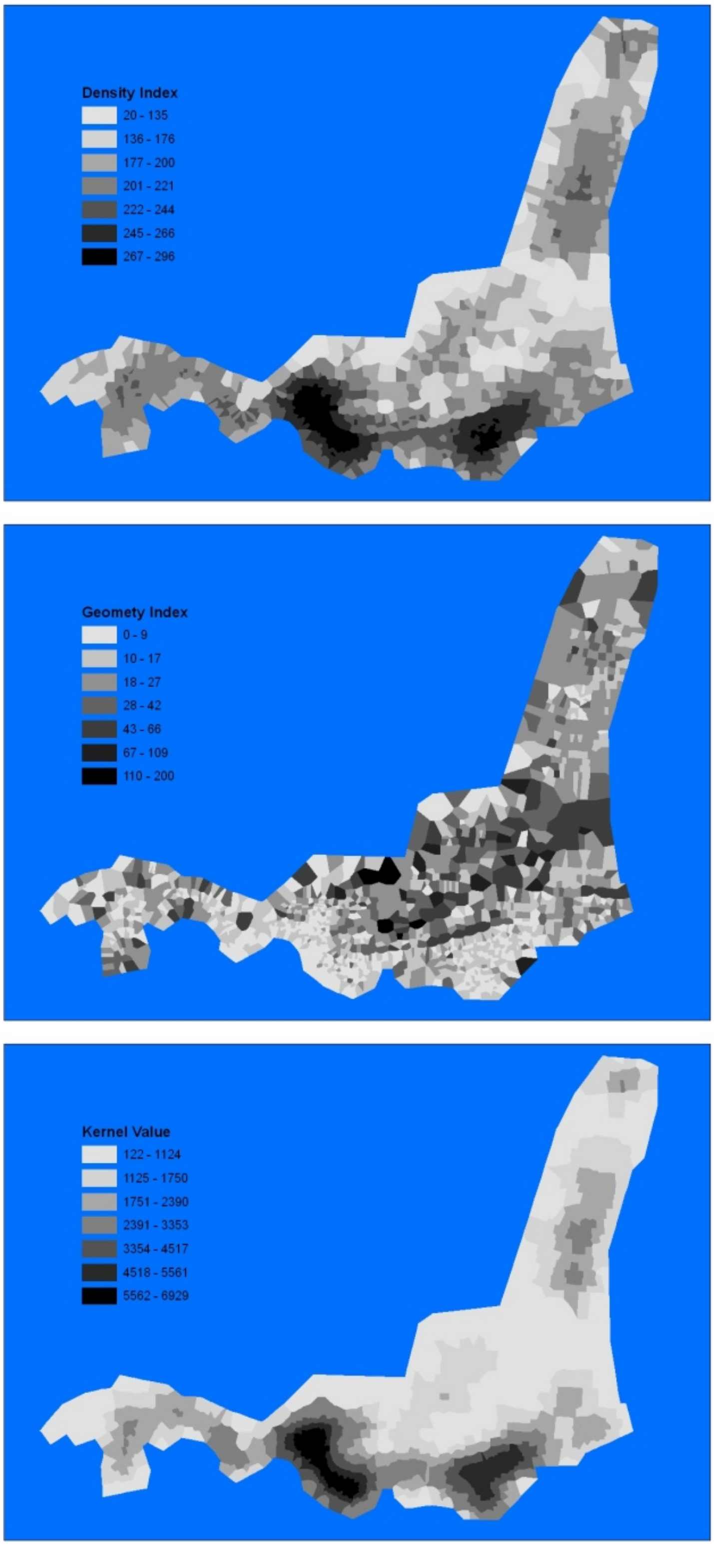


Figure 4.24. Density index, geometry index and kernel value thematic maps, with the order from top to bottom, converted into the raster format.

The generated thematic raster layers are imported to the utilized software. The analysis is carried out with feature (range) bandwidth, spatial bandwidth, and a minimum region area (in pixels) as input parameters. The spatial bandwidth (r) defines the search window by (2r+1) x (2r+1). The spatial bandwidth value used is 50 and the minimum region value is 10000. Larger or smaller region results could be obtained by entering different minimum region values.

There are three main outputs of the utilized software. These are filtered image, which constitutes the segmentation input, segmented image, and the other output is also an image with segment boundaries (figure 4.25, figure 4.26, and figure 4.27). The last polygon vector layers of all three alternative approaches (figure 4.25, figure 4.26, and figure 4.27) are obtained through raster to vector conversion function by using the segmented image outputs.

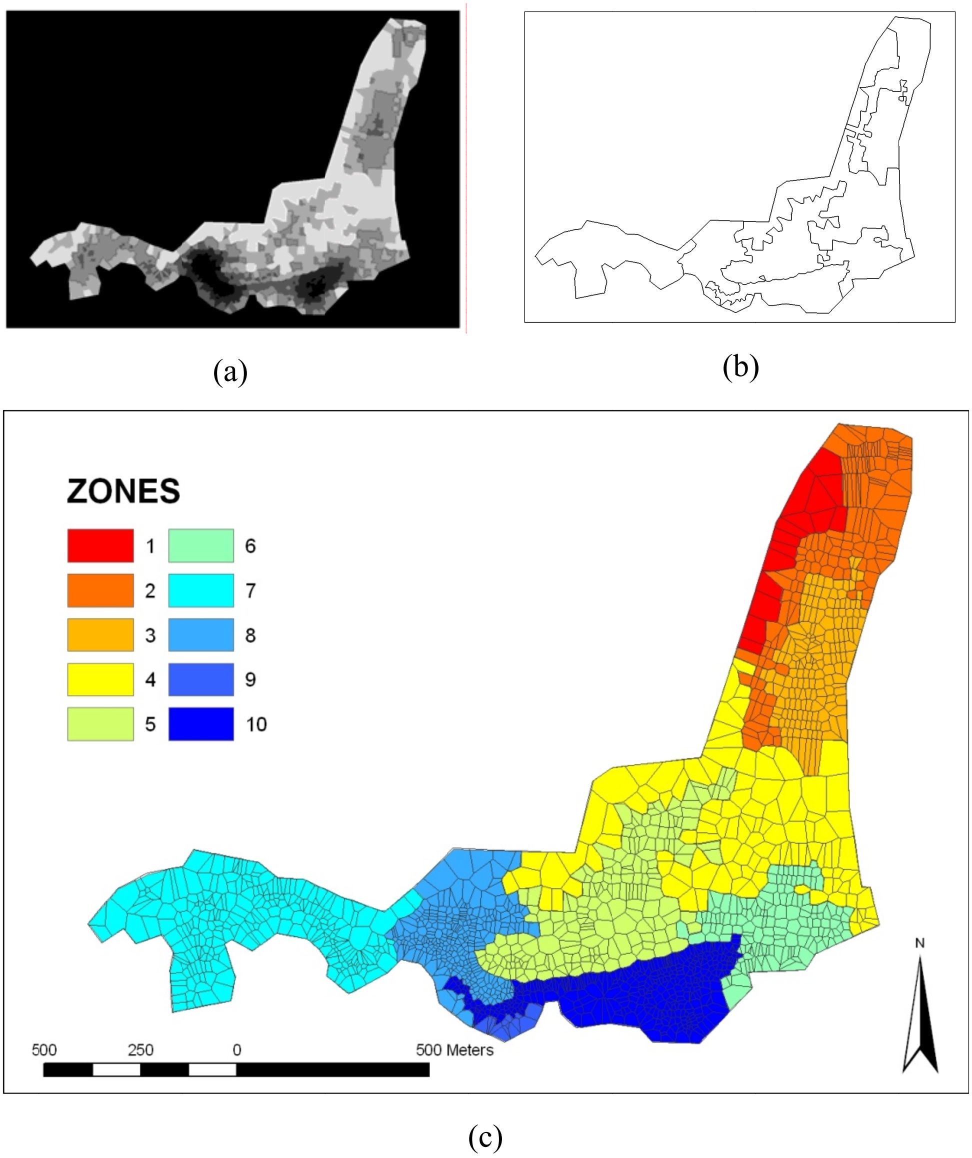
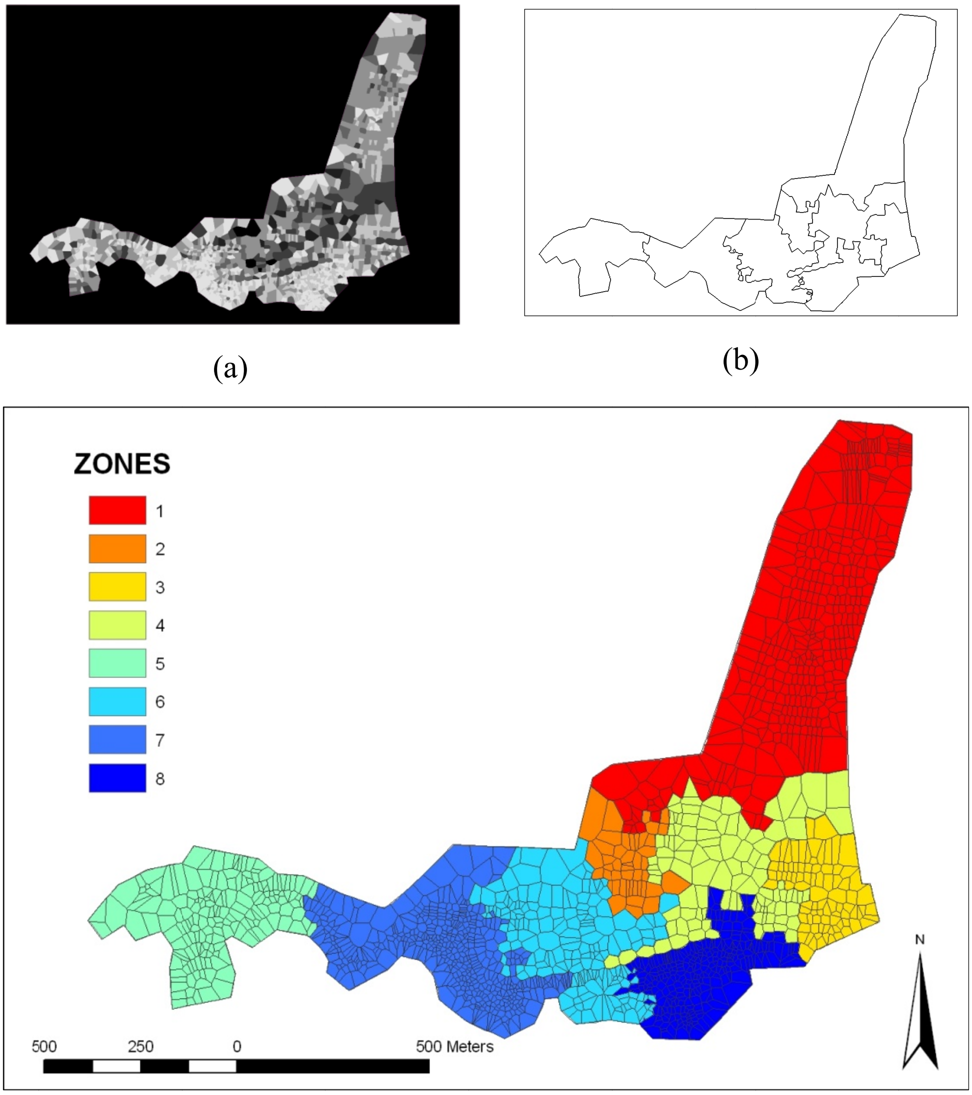


Figure 4.25. (a) Filtered image, (b) segment boundaries and resultant (c) zonation based on building density index approach



(c)

Figure 4.26. (a) Filtered image, (b) segment boundaries and resultant (c) zonation based on building geometry index approach

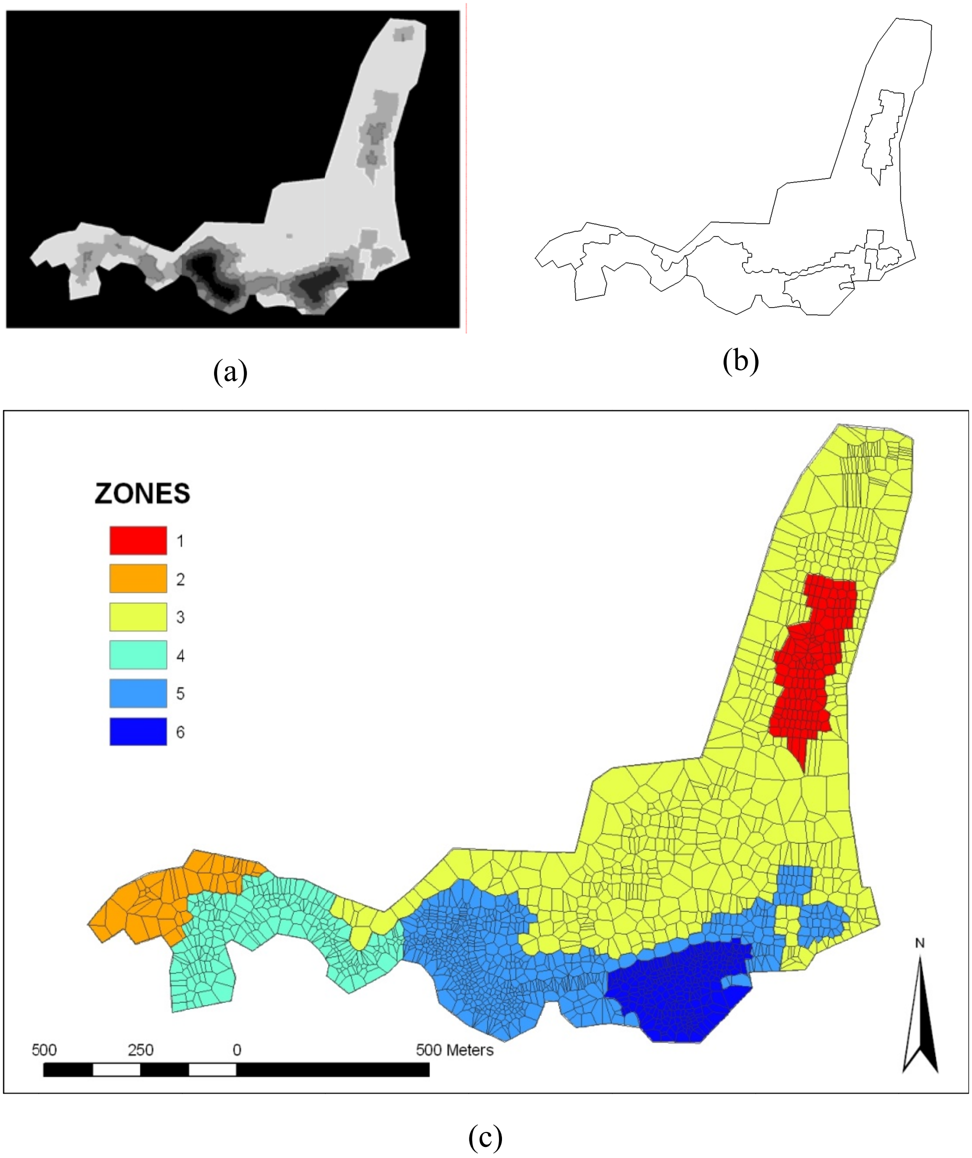


Figure 4.27. (a) Filtered image, (b) segment boundaries and resultant (c) zonation based on kernel function approach

4.3.1.3 The Comparison of the approaches

The SOM method is a very robust method for the clustering of the multi-dimensional data. Nevertheless, the applied tests showed that the spatial information used in the GeoSOM step of the utilized software causes highly correlated results. The zonation results of all three SOM approaches give approximately the same zone borders.

The method of image segmentation with building density index gives the most appropriate Sub-urban zone results. This comparison is made by considering the similarity between the application outputs and the zonation based on expert opinion result.

In implementations chapter, the second phase (object representation) of the framework application, the tsunami case needs a two-level object representation evaluation. The zonation results of the mean shift approach provide the needed input zone definitions; each of the four different approaches of the mean shift method is used to get at a final LoD definition.

CHAPTER 5

NEEDS ASSESSMENT

Once the conceptual 3D models is established (i.e., with respect to the types of objects to be modelled and their resolution), the next requirement to be satisfied in the framework is the generation of the corresponding 3D models. In this section, the available data and outputs are compared with the results obtained from the data/processes needs analyses.

In a 3D urban modeling process, the focus lies on the management of multi-scale geo-referenced 3D urban data. The following factors influence the model characteristics, which may vary depending on the purpose of visualization:

- Modeling environment,
- Spatial accuracy needs,
- Temporal accuracy needs,
- Model data source,
- Urban terrain model,
- Building detail level,
- Modelled city furniture or infrastructure

The modeling environment can be CAD, GIS or other visualization environments. The required spatial accuracy may vary from the order of millimetres to the order of kilometres in the spatial domain and from hours to decades in the temporal domain. The available data source is one of the most important parameters, which determines the characteristics of 3D urban model. Data gathered with an active or passive sensor change the method of model generation. If the desired detail level is high, different supplementary spatial and attribute data is required. The modelled city furniture and infrastructures are inevitable urban model parameters in a 3D visualization for disaster risk communication.

Sensor products, available vector data and methods for reconstructing 3D urban models are important factors in the proposed framework. Risk managers have to be aware of how much effort and money is needed to obtain an effective 3D model for visualisation. In practice, this means that a method based on the products of laser scanning or optical sensors are more likely to be better matched with the resources of a specific municipality. The selection of products is also dependent on the desired LoD. For instance, 3D models textured with images always require the use of optical sensors. The efforts required for creating a detailed 3D model (e.g., buildings in LoD3) differ significantly from the efforts needed to obtain a LoD1 model. The proposed framework aims to provide a guideline for risk managers in municipalities make the most appropriate decisions regarding the resolution of the 3D model.

For example, the required new data and model can be discussed with respect to the resources of the municipality. Assume that the visualisation of a given hazard may require a 3D model with LoD4 resolution. However, the municipality may only have high-resolution stereo aerial images. To come up with the desired product, they will need additional data such as ground images, building data that contain detailed indoor information, software for image processing of stereo images, 3D geographic modeling software and visualisation software to combine detailed 3D geographic objects and other spatial outputs like terrain models. Moreover, this modeling process will reveal that there will be a need for a considerable amount of human resources for the use of sophisticated software. It is up to the decision makers to find the best balance between the required model and the available resources.

In the study, different 3D urban modeling methods are analyzed with a sample application in order to compare the data and process needs. In this chapter, these modeling methods are given after the 3D urban modeling background section.

5.1 Background for Three-Dimensional Data Structures for Geo-Representation

Three-dimensional spatial representation is a branch of solid geometric modeling. The way in which spatial data are numerically stored, linked, and processed in a computer constitutes a spatial representation (Lattuada, 2006).

The literature on solid modeling involving spatial representation can be summarized as follows. First, Jones (1989) reviewed available three-dimensional data structures. Bitzer and Pflug (1989) and Pflug and Harbaugh (1991) represented the geoscientists' view on the spatial representation and simulation of geological formations. Next, Turner et al. (1989) focused on the effect of scale on the representation of geo-phenomena. In another study, Vinken (1992) reviewed the digitization side of geological mapping. Ozmutlu (1999) surveyed the studies, which focused on geological characterization, geo-representation, simulation and virtual environment creations for again geosciences. Finally, Schmidt and Gotze (1998) assessed the requirements of geophysics for three-dimensional solid modeling.

In the literature of three-dimensional spatial representation, there are two main approaches to classify the modeling techniques. According to the first approach, these representation techniques are divided into two main classes, like their two-dimensional complements – vector and raster. These are boundary techniques and volume techniques (Raper, 1989). The other approach divided solid modeling techniques into three (Requicha and Volcker, 1982; Requicha and Rossignac, 1992). These are constructive, boundary, and decomposition techniques. In fact, these two classifications pointed out the same content; the constructive and boundary methods of the second classification are aggregated with the boundary techniques class in the first classification. Besides, decomposition methods are given as volume methods in the first one.

Constructive methods are based on simple primitives. Primitives can be used to make a shape using “constructive solid geometry” (CSG) methods, based on union, intersection and Boolean operations. Boundary methods are based on decomposition of the modelled object to the faces, meeting at edges, which join vertices. Representations using these topological primitives construct boundary representations (B-reps). B-reps have certain characteristics. They must be closed, orientable, non-self intersecting, topologically bounded and connected. Boundary approaches are suitable for spatial representation since they are conservative and efficient, and they adapt to variable data densities. Finally, the decomposition approach involves splitting the model objects into “horizontal slices”, “prismic columns”, “volume primitives” or regular cubic cells known as “voxels” (Requicha and Rossignac, 1992).

The characteristics of the modelled 3D spatial objects define the utilized 3D modeling approach. The discrete or continuous characteristics of the phenomena to be modelled need different modeling approaches. While the B-reps of boundary techniques are suitable for discrete objects, the voxel of volume techniques works for phenomena, which vary in space (Raper, 1989).

As indicated in many different parts of the dissertation, semantic definitions about city object to be used in the models of the proposed 3D city modeling framework are constructed on the CityGML of OGC. Moreover, spatial modeling properties of urban objects in CityGML are represented by the B-Reps, which is a boundary method of 3D solid modeling (Foley et al, 1995). Therefore, 3D modeling technique that was considered in the dissertation is limited with B-reps.

5.2 3D Urban Modeling

3D city modeling is an active research topic. The main focus lies on the management of multi-scale, large area, and geo-referenced 3D models.

Architecture, engineering, construction, and facility management (AEC/FM) domain address more detailed 3D models. On the other hand, computer graphics concentrates on the visualization of 3D models in which geometry, topology and data management and manipulations are the main focuses. Geometry and topology issues of 3D objects was investigated in detail by Molenaar (1992), Zlatanova (2000), Herring (2001), Oosterom et al. (2002), Pfund (2002), and Kolbe and Gröger (2004). The management of multi-scale models was discussed by Coors and Flick (1998).

3D city models are generally used by government agencies for urban planning, public safety studies such as fire propagation, commercial usages including phone, gas or electric companies, etc. Most of these examples are interested in modeling buildings, terrain and traffic network in the city model. Models, used for visualization, can be grouped into three with respect to their data acquisition methods (Hu et al., 2003; Kerle et al., 2008; Poullis and You, 2009). These methods are;

- Passive sensors,
- Active sensors
- Various combinations with CAD

Passive sensors record radiation emitted by the Earth to photographic images. The determination of the geometric properties of objects from these images is the main concern of the science of photogrammetry. Photogrammetric methods are cost-effective in large-scale 3D urban models. Terrestrial, panoramic and aerial image methods are in this group of modeling. There are some example models that are created from panoramic photos. The basic data source for photogrammetric methods is aerial images which provide reliable footprint and roof height information for each building in the model area. Today, 3D city models from aerial image studies generally focus on extracting accurate roof models from images. Lin and Nevatia's model predefines L-, T- and I-shaped roofs and assigns the most suitable roof shape to the examined building's roof (Lin and Nevatia, 1998). Stereo aerial images could also be useful tools for extracting 3D objects (Baillard and

Maître, 1999). Lack of information on building façade requires additional sensor data to be acquired for visual realism. Manual and semiautomatic methods produce more mature results than fully automatic systems. Knowledge-based and machine learning algorithms are another hot research area for the atomization of this kind of systems. Nevatia and Huertas (1998) and Bellman and Shortis (2002) are two examples for such applications. Both of them used knowledge and machine learning algorithms to improve the performance of automatic building extraction.

Active sensor could be defined as a detection device that emits energy capable of being detected by itself. Basically there are two kinds of active sensors used for 3D city modeling: Ground-based and airborne-based. Ground-based systems are ideal for vertical textures especially for historical structure façades (Frueh and Zakhor, 2001). However, they provide less accuracy for upper portions of tall buildings and these systems could not obtain roof and footprint data. Light detection and ranging (LIDAR) technology is a typical airborne-based sensor and is used for 3D city modeling studies. LIDAR technology has great potential for the atomization of modeling issues. However, because of the lack of available data, this modeling method could not be investigated in the thesis.

Most city model applications use various data sources, which require hybrid usage of different sensors with CAD data. Each of these data sources and corresponding modeling techniques has advantages and disadvantages (Ribarsky et al., 2002). Tao (2006) and Kerle et al. (2008), state that the integration of different sensor products can be in the form of simple overlay operation or extraction of multi-data information. The application areas of this integration can increase the dimensionality by using DSM and 2D images, and furthermore, increasing spatial resolution is achieved by using high spatial resolution panchromatic images with multispectral images in relatively low spatial resolution and finally multi-criteria analysis to assess the natural disaster risk by considering various elements at risk.

As declared at the beginning of this chapter, three methods of 3D urban modeling are tested with a sample application. These three methods are;

- Narrow baseline photogrammetry
- CAD-based 3D modeling
- Modeling by stereo images

The first and the last of the listed methods are examples for modeling approaches with passive sensor products. In addition, the second one could be grouped within the hybrid modeling approach. Narrow baseline photogrammetry method was tested with a single building modeling, and CAD-based 3D modeling methods were used in the application of Eskisehir Earthquake visualization. General information about these applications is given in this chapter while explanations with greater details are located in the applications chapter. Stereo image modeling method, which is the last tested urban modeling method, was tested on a small urban texture in Eskisehir.

5.2.1 Narrow Baseline Photogrammetry

The basic operating principle of the "Narrow Base-line Photogrammetry" method, the first modeling study to be used to create models, involves the following steps:

- The calculation of *interior orientation parameters* (f, X_0, Y_0, Z_0) obtained by camera calibration

- Image normalization, *brightness values* of the normalized images are used to render point clouds

- The calculation of the *exterior orientation parameters* (m_{ij}, X_i, Y_i, Z_i) by using key points or marked target points

- Obtaining the height (Z) information from disparity images (Figure 1)

At the last step, the above mentioned information constitutes the entry of the co-linearity equations (equations 9, 10 and 11) to calculate information on x, y, and z positions and the brightness values of each point in the end point cloud.

$$x - X_0 = -f \frac{m_{21}(X - X_i) + m_{22}(Y - Y_i) + m_{23}(Z - Z_i)}{m_{31}(X - X_i) + m_{32}(Y - Y_i) + m_{33}(Z - Z_i)} \quad (9)$$

$$y - Y_0 = -f \frac{m_{21}(X - X_i) + m_{22}(Y - Y_i) + m_{23}(Z - Z_i)}{m_{31}(X - X_i) + m_{32}(Y - Y_i) + m_{33}(Z - Z_i)} \quad (10)$$

$$z - Z_0 = -f \frac{m_{21}(X - X_i) + m_{22}(Y - Y_i) + m_{23}(Z - Z_i)}{m_{31}(X - X_i) + m_{32}(Y - Y_i) + m_{33}(Z - Z_i)} \quad (11)$$

where, f, X_0, Y_0, and Z_0 interior orientation parameters (focal length and focal point coordinates), m_{ij}, X_i, Y_i, and Z_i exterior orientation parameters (imaging point coordinates and rotation parameters), X, Y, and Z control point coordinates and height values derived from the disparity images are used to compute x, y, and z coordinates of points in the point cloud (El-Sheimy et al. 2005).

Narrow Baseline Photogrammetry method was tested on a small building in METU campus area. As described in the methodology part, the basic data of the study are the photos of the objects modeled, which have high rates of overlap, obtained during the field work. In addition to photos, as in this case, if the modeling object has a geographical position component, the control point coordinates used for geographical engeocoding is another data set.

The method involves two basic phases. These are: 1) field study, and 2) processing of the collected data in the field (figure 5.1). The field study, the first phase of the method, starts with a preparation work. At this stage, the properties of camera lens and the size of coded targets are determined according to the modeled object properties. Taking high overlapping rate photographs from all aspects of the modeled object with the specified fixed focal length camera constitutes the next field study work. The last work item in the first phase is the collection of spatial position coordinates which will be used for positioning the generated point cloud and the models. This is achived by using global positioning systems (GPS) with sufficient precision. In the absence of a spatial content of the modeled object, there is no need to collect the point coordinates.

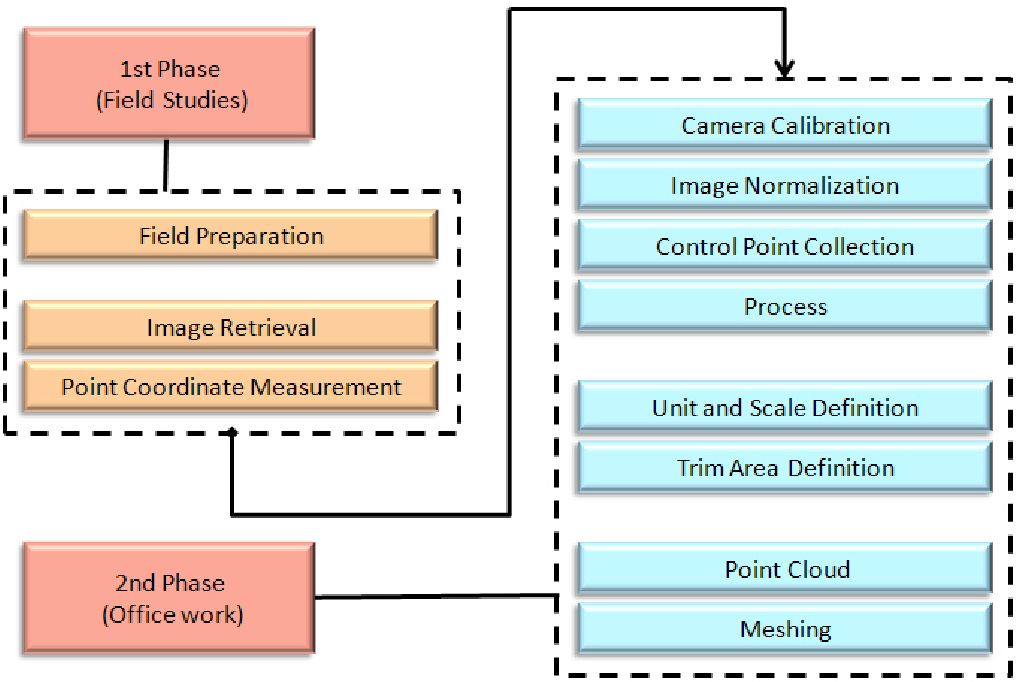


Figure 5.1. The phases of the study and related work steps

In the second phase of the method, the processing of the collected data starts with the calibration of camera. Camera calibration is the process of finding the correct parameters of the camera lens that are used to obtain field photographs. These parameters are;

- Focal Length
- Format Size
- Principal Point
- Lens Distortions

By the calibration of camera lens, lens offsets, shifted center point, and non-square cell distortions are removed from the resulting images. Camera lens calibration is performed through horizontally and vertically framed photos taken from each of the four sides of the calibration grid provided by the employed software (Photo Modeler Scanner). The resulting calibration parameters are stored in a file, created by the software after the calibration process, which can be used in all similar projects that involve photos taken by the same camera and lens. After the camera calibration, the normalization of the images uploaded to the system is the first transaction to be carried out. The normalized images are used to collect control points. The control points to be used for geocoding of images may be key points collected from the images as well as the coded targets that gave reliable results in such studies. The distribution, number and level of accuracy of the control points used are critical components for the accuracy of the model. In the processing step, control point's coordinates, interior orientation parameters which are calculated with camera calibration, exterior orientation parameters which are calculated by control points, and the depth (z) values which are calculated by the use of disparity images form the entry parameters of the utilized mathematical model (co-linearity equations) are required to find the 3D positions of the points of point cloud. At this stage, a masking area, defining only the required fields on the image, is used to reduce the processing load of the creation of point cloud and the modeling. The scale and the measurement units of the study are determined by using two control points; the actual distances between these points are known. A point cloud of points which has known x, y and z coordinate values is the result of spatial engeocoding process. In addition to the coordinate values, each generated point of resultant point cloud has brightness values from the obtained images. At the point cloud construction stage, the utilized software provides two different levels of point cloud settings, namely basic and advanced. User can define sampling rate and depth range in the basic level point cloud settings. Moreover, it is possible to set sub-pixel sampling, super-sampling factor, matching region radius, and texture type settings at the advanced level.

The second phase of studies result in the 3D wire frame (meshing) construction from the generated point cloud. Meshing steps and the summary of these steps are: a) *Filter*, deleting noise points, b) *Register and Merge*, building a point network by bringing different point clouds together, c) *Denoise Point Cloud*, obtaining a denoise point network while preserving the edges and corners, d) *Decimate Point Cloud*, reducing the points while maintaining the representation, e) *Mesh Point Cloud*, the triangulation of the point network, f) *Decimate Triangles*, reducing the triangles while maintaining the representation, g) *Fill Holes*, closure of space areas smaller than the specified threshold value, h) *Unify Normals*, unifying the triangle normals in the generated triangle mesh, i) *Fill Fjords*, filling the long thin gaps at the edges of the mesh, j) *Smooth*, deleting the noises and softening the mesh while maintaining the sharp edges, k) *Sharp Smooth*, softening the mesh while maintaining the sharp edges more than the previous step, l) *Contours*, creating co-spaced contour lines.

Photos were taken by a 1.6 multiplication factor (APS-C Sensor) camera (Canon 30D) with a 10-22 mm zoom lens. The full building seen in all photos is the basic heed. In order to collect control point positional information, the GNSS system was used, which is capable of using TUSAGA (CORS-TR) GPS correction broadcasting network so that the spatial accuracy of the system is about 1 cm.

The key points obtained from the building were used as target points for the image geocoding. Due to the absence of a fixed value lens and the absence of the coded targets, it has not been possible to model the structure as a whole in this application. Successful results were obtained for areas covered by relatively proper images in terms of geometry (figure 5.2 a and b). The resulting triangular mesh was visualized in Google Earth environment by using the coordinate values collected via GNSS (figure 5.2 c and d).

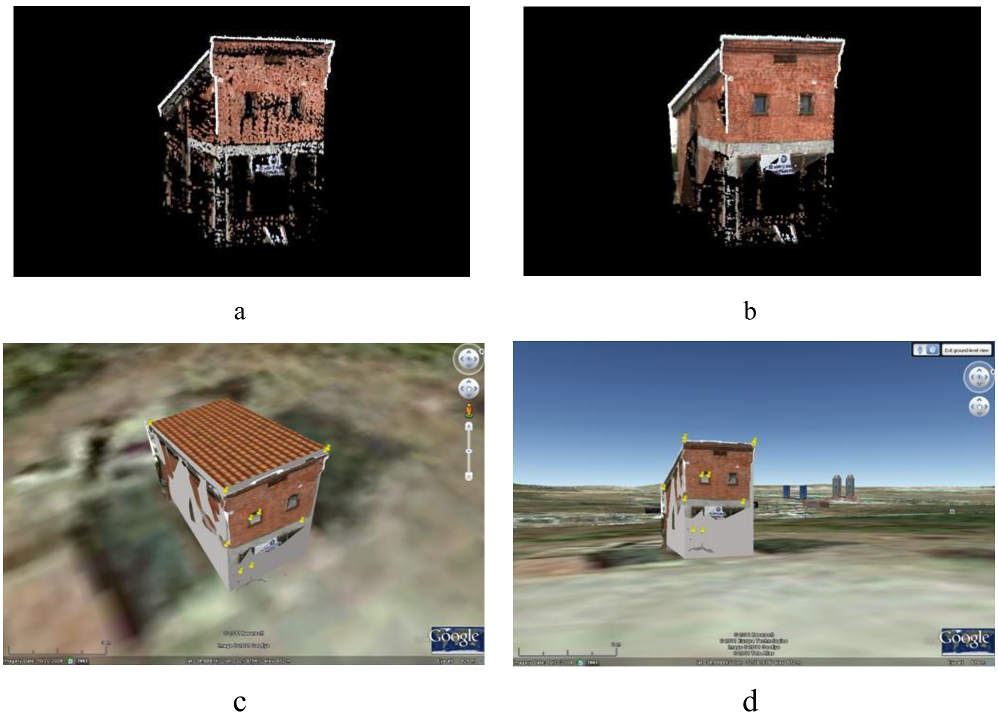


Figure 5.2. The results of the building application

The factors that affected the success of the photogrammetric technique used in this study can be listed as camera resolution, the method of camera calibration, angles between photos, photo orientation quality, and targets.

5.2.2 CAD Based 3D Modeling

Today 2D GIS data are often available in most of the cities. Many model applications use this data for their applications (Norbert and Anders, 1997; George, 2001). 2D CAD data provide accurate urban features and boundary data. Generally, boundaries are usable data sources for image segmentation. The limitations for CAD systems can be listed as attribute and spatial data management capabilities, and spatial modeling. However, spatial data, which forms the basis of the study, has two main components, which are graphic and attribute. The CAD data structure can not store information on the relation of these two components of the data; as a result, CAD does not allow the management, the analysis and the modeling of the attribute information related to the spatial data.

The main strengths of CAD systems are the editing capability of graphical features and clear and detailed graphical presentation controllability. Graphical presentation is important for the proposed purposes of this dissertation and CAD properties, which are used for the generation of the 3D city models and the visualization of the related data.

Four main data sets were used in this study, which were;

- Façade images
- Building footprints
- Building heights
- Street layer

Façade Images were used to improve the realism of the 3D model in CAD environment. These façade images were collected from the related buildings. The compact digital camera used to collect façade images was Canon Powershot Pro1. The technical specifications of this camera are;

- 8-Megapixel CCD for images up to 3264 x 2448
- 28-200mm equivalent f/2.4-3.5 7x zoom
- 15 - 1/4000 sec shutter speed

Building footprints layer that was acquired from the urban information system of the municipality of Odunpazari, was extruded by using the collected building heights. To measure the building heights, TruPulse professional rangefinder was used. This compact and lightweight laser instrument measures the height of the target by using its height routine. Another vector data, also acquired from the urban information system, were road layer, which were used to create digital 3D city scenes with other building related data.

The 3D city model in CAD provides a Virtual Reality (VR) environment. In order to create VR environments, first of all digital 3D scenes have to be constituted (figure 5.3). After the creation of the solid model by using building heights, the façade images were utilized to map the external surfaces of 3D solid buildings. in the image collection stage, different aperture values were used to gain homogeneous exposures of all images.

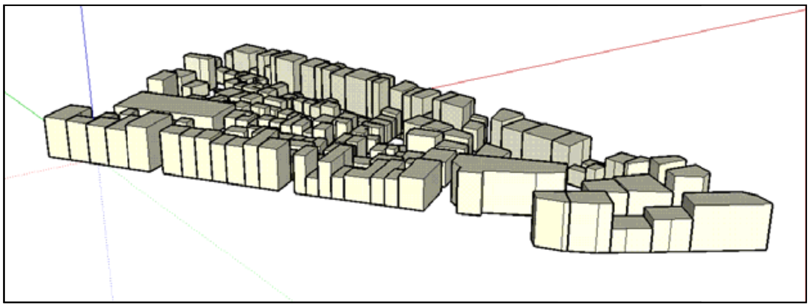


Figure 5.3. Building a solid model

Difficulties that were faced during field data collection can be listed as:

- Difficulty in photographing some buildings which have official secrecy (i.e. police and military buildings)

- Dense and tall buildings in narrow roads, with perspective distortions on the façade images

Before mapping the field images to the building surfaces, the collected images need to be corrected for geometric, atmospheric, radiometric and angular distortions to improve the image quality and to remove the distortions. The image rectification functions applied can be listed as cropping, contrast enhancement, rotating and perspective adjustment. Each image was manually rectified to be a façade image for 3D city model (figure 5.4). After the operation of image rectification, four corner points of the images were used for coordinate system transformation of the related façade image. Figure 5.5 represents the resulting 3D city model, extruded buildings and mapped façade images.

(a) (b)

Figure 5.4. (a) Before and (b) after image rectification of an example façade image from the study area

Figure 5.5. The general view from the 3D city model

The generated model can easily be exported to the GIS environment for providing the building façade and geometry.

5.2.3 Modeling by Stereo Images

Stereoscopy is the branch of science dealing with images to produce a three dimensional visual model (Manual of Photogrammetry, 1980). Stereoscopy with images is used in order to produce DEMs, or object extraction. The accuracy obtained from stereoscopic processing is closely related to the parallax inherit in the stereo images. There are three solutions to obtain stereoscopy with images (Toutin, 1999). These solutions are;

- Adjacent-track stereoscopy
- Across-track stereoscopy
- Along-track stereoscopy

If the utilized sensor lacks a steering mechanism, it can not acquire stereo images in the same orbit; therefore stereo imaging can only be possible with successive orbit images in these types of sensors. This stereo image acquisition method is named as "adjacent-track stereo". This method allows poor base height ratios (B/H) that are between 0.1 and 0.2.

Like the previous method, in the across-track stereoscopy, different orbits are used. However, in this method non-successive orbits are used rather than successive ones.

This kind of images can be obtained by using steerable and rollable sensors. Images acquired by using such sensors have perfect B/H ratios, which are 0.6 to 1.2.

In contrast to the previous methods, in the along-track stereoscopy method, stereo images can also be acquired on the same orbit by steering the sensor or by changing the pitch of the platform to the forward and backward directions (Ok, 2005). Several satellites such as ASTER and IKONOS have the ability to acquire stereo images. Images obtained from along-track stereoscopy have fine B/H ratios that are appropriate for DEM generation and object extraction.

The method was applied on a housing texture with sparse, low-rise buildings in Eskisehir city skirts. Pan-sharpened stereo satellite images from IKONOS with 1-meter spatial resolution (figure 5.6) were used to construct stereoscopy to extract the desired urban objects.

(a) (b)

Figure 5.6. (a) Left and (b) right odds of the IKONOS stereo image

The application was executed in the Leica Photogrammetry Suite with Erdas Imagine 8.7 and Stereo analyst module software (figure 5.7). The software provides all functions of image pre-processing and digital image analysis with stereo analyst module stereo image handling capabilities added to these basic necessary tools.

Figure 5.7. The study area in the Leica Photogrammetry Suite Stereo analyst module user interface with utilized IKONOS stereo satellite images.

The generated stereo block file was used to extract buildings and other man-made urban objects like roads and field borders (figure 5.8). Urban object extraction is a manual process. 3D view can be possible through stereo image software and hardware (stereographic card, emitter and glasses) infrastructure. Even if the needed software and hardware are available, 3D view experience directly affects the positional accuracy (Ergin, 2007).

Figure 5.8. The result of the 3D digitizing process by using stereo image

The generated 3D objects can be extracted to the GIS environment in VRML or ASCII format. In the first case, each of the 3D digitizing projects can be handled as a single object in GIS environment. To avoid this, the conversion of the results to the ASCII format is sole solution. This solution works properly for 3D objects with no façade textures.

There were no façade textures in case of stereo image modeling; therefore, ASCII conversion was preferred. In the generated ASCII file, to export the extracted objects to the GIS, x, y and z positions of the vertex point of each part (each face surface of 3D object in boundary representation) were given with collected or assigned attribute information. A sample object representation is given below (figure 5.9). In this case, the sample object has five faces with four corner points (figure5.10) (in the representation the fifth one is the same with the first one). Moreover, there are four pieces of different attribute information, attached to the geometric object description.

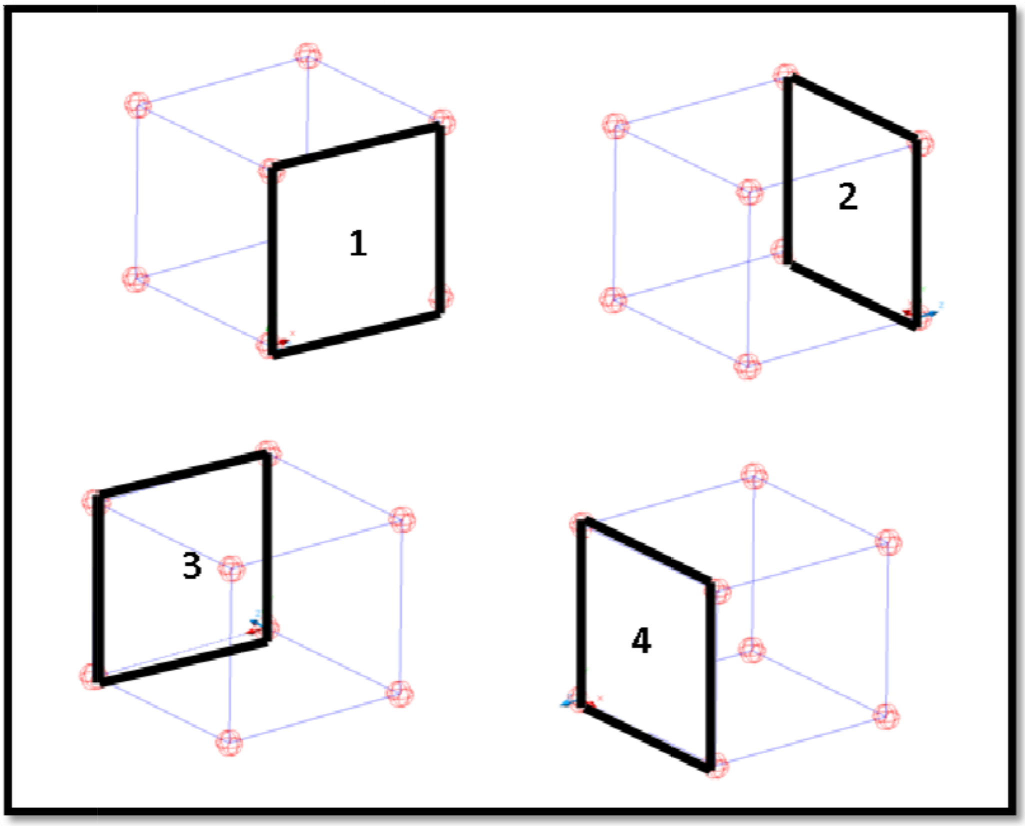


Figure 5.9. The order of boundary face numbering

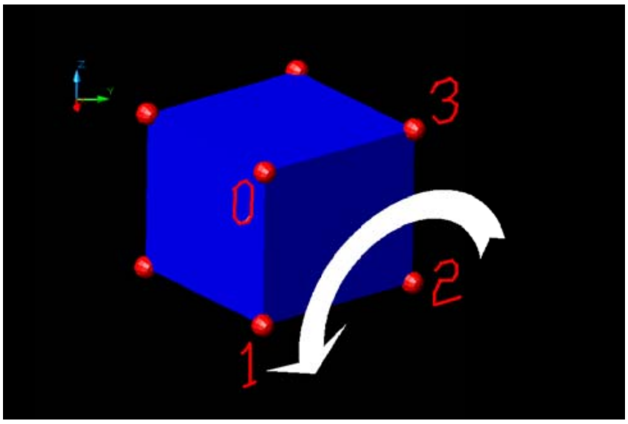


Figure 5.10. The order of vertex point numbering

5.2.4 Comparison of the Tested Methods

3D urban modeling methods are tested with a sample application. These three methods are compared based on the GIS components, which are software, hardware, live-ware and data, and costs to apply the method. The other comparison criteria are the appropriate scale of application and interoperability (table 5.1).

Table 5.1. The comparison of the tested 3D modeling methods

	Cost				Scale	Interoperability
Method	**Soft-ware**	**Hard-ware**	**Live-ware**	**Data**		
Photo.	Medium	High	High	High	Building	Hard
CAD	Low	Low	Low	Low	Urban	Easy
Stereo	High	High	High	High	Building	Medium

In the light of this comparison, CAD modeling appears to be the easiest and the most cost-effective modeling method for wide-area applications. However, the results of the other 3D modeling methods are at the LoD1. In the event of need for more detailed modeling approaches, the resultant of these two methods needs additional CAD operations like texture mapping and indoor data integration.

CHAPTER 6

IMPLEMENTATIONS

Two natural hazard cases were studied within the scope of this study to see the operability of the proposed framework. These implementations are Eskisehir Earthquake and Fethiye Tsunami. As described in the section of the hazard related components of the chapter 3, according to the process characteristics of models there are two different points of view. The first one is the static model and the second one is the dynamic model. In the selection of two implementation cases that were studied, special attention was paid to finding one sample case for each approach. The implementations are presented in the same order as the framework's flow manner. After the study area assignment is completed, the determination of the user and elements of the visualization are performed. In the next step, the representation requirements of visualization objects are analyzed. Then the needs for data and processes are defined in the light of data inventory and the studies on the utilized modeling method. Finaly each framework implementation case is completed with discussions about the creation of the intended 3D urban model.

6.1 Earthquake Implementation

6.1.1 Background

The first application is visualization for the earthquake case in Eskisehir, Turkey. In this application, a visualisation application is required to be built for the users in the municipality. Therefore, the users involve the municipality staff, such as urban planners, cartographers and sociologists. They need a clear view of the distribution of vulnerable regions throughout the city. The municipality of Eskisehir has an urban information system infrastructure, so they have extensive data and software (planning, cartographic and GIS software). A 3D urban model environment is used to visualize the calculated social, physical and accessibility vulnerability indexes of each building object (Kemec and Duzgun, 2006a; Kemec and Duzgun, 2006b; Duzgun et al., 2011). Duzgun et al. (2011) proposed a framework for integrated vulnerability assessment for urban environments. According to this framework, vulnerability to natural hazards is not only considered as structural fragility but also as socio-economical vulnerability and vulnerability due to accessibility to the critical services like hospitals or fire brigades.

6.1.2 Study Area

Eskisehir is one of the most important industrial centres in Turkey. 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 central Turkey with a population of over 500.000, according to the 2000 census. The greatest part of the settlement in the city is located on alluvium. The greatest earthquake that has ever occurred in the city was in 1956 (Ms: 6.4). The pilot area is a part of the city centre, covering some portions of the Akcaglan, Akcami and Pasa neighborhoods, and it has various kinds of city development textures including low-rise, historic buildings and high-rise apartments. There are nearly 400 buildings in the application area. (figure 6.1).

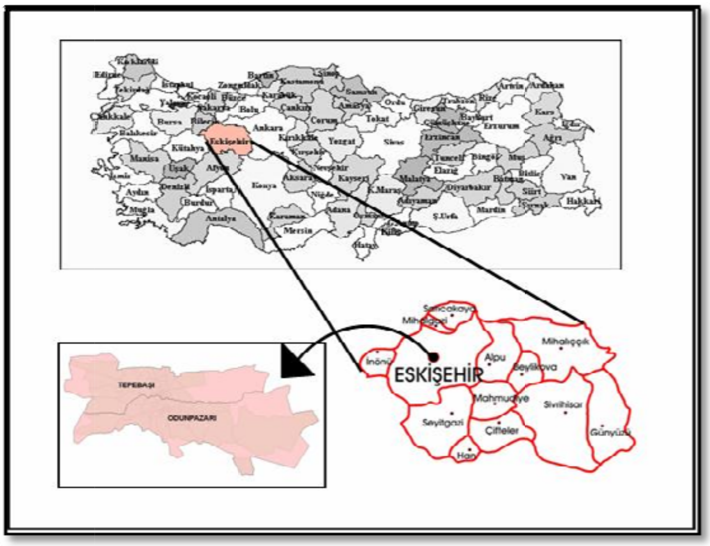


Figure 6.1. Eskisehir Study area

6.1.3 Application of the Framework

6.1.3.1 Phase I - Definition of visualization components

As mentioned above, the users are the municipality staff, and they can be both technicians and non-GIS experts. In general, they need relatively realistic 3D urban models. The basic elements at risk recognized are buildings and socio-economic structures of people living in the buildings. To construct a realistic urban environment and to express the aim of the visualisation model, the objects are defined as;

- Buildings
- Relief
- City Furniture
- Transportation
- Vegetation

6.1.3.2 Phase II - Object representation

After the analysis of the requirements for model object definitions representation is completed, urban-related criteria group of the decision rule constitutes the starting point of the analysis.

The attribute of d_s *(disaster susceptibility)* refers to the spatial density of the disaster, and it is defined by the physical susceptable zones of the urban land. A probabilistic approach was applied by Özmen et al. (1997) to find the earthquake hazard zones for a 50-year period with a confidence level of 90% (figure 6.2). According to this study, Eskisehir is located in the fourth severest hazard zone on the scale of 1-5, where five indicates those areas under the biggest danger; hence, *v* was assigned a value of 4.

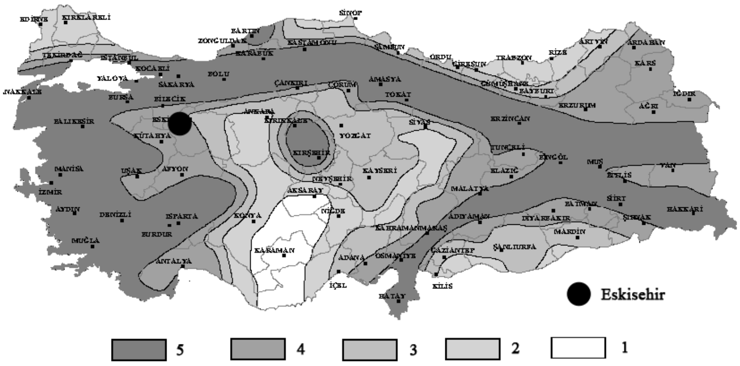


Figure 6.2. Turkey earthquake hazard zones (Özmen et al., 1997) for disaster susceptibility (d_s) attribute

The evaluation of the attributes *p* and u_{ae} was conducted for 339 settlements in Turkey. Data processing steps to compute area sizes and population densities include a map projection conversion of a global spherical system (WGS84) to a country cartesian system (UTM) and a spatial join operation between urban extent polygon objects and urban point objects using settlement population information. The calculation of the area and the population density, u_{ae} and *p*, respectively, constitutes the calculation step of urban criteria attributes in process of defining the complete model attributes for the Eskisehir application. To define p and u_{ae}, a geometric interval classification was applied to convert the measurements to the reclassified attribute values. The relation between the areal extent and the needs of the model detail is not linear; therefore, the areal extent adds complexity to the urban system, necessitating a more detailed modeling approach. The same degree of added complexity is valid for the population density parameter. It was determined that a geometric value/utility function better suits both of these attributes than a linear one; the geometric interval classification calculates the intervals by subtracting the minimum from the maximum intensity value (Joseph, 2007). The conversion coefficient for the dataset is calculated by dividing the result of the previous interval by that of the current interval.

The statistics related to the population density attribute:

The minimum population density value is 0.65 per/ha and the maximum is 108.05 per/ha, with a mean of 6.88 and a standard deviation of 6.84. Eskisehir, with a population density of 14.11 per/ha, is classified as $p = 2$ (table 6.1 and figure 6.3a). In this attribute approach, high population density values map to low p attribute values, indicating that they require intensive modeling approaches.

Table 6.1. The distribution of population density values for earthquake

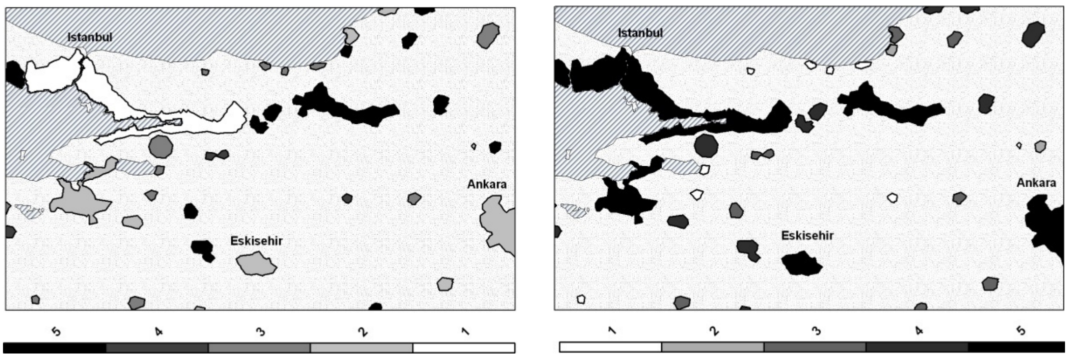
Classification	# of settlements	%	p
0.65 < pop_dens ≤ 4.47	**108**	**0.31**	**5**
4.47 < pop_dens ≤ 5.30	**46**	**0.14**	**4**
5.30 < pop_dens ≤ 9.12	**119**	**0.35**	**3**
9.12 < pop_dens ≤ 26.74	**64**	**0.19**	**2**
26.74 < pop_dens ≤108.05	**2**	**0.01**	**1**

The statistics related to the areal extent attribute:

The minimum urban areal extent is 726 ha and the maximum is 199632 ha, with a mean of 12736 and a standard deviation of 21944. The value of u_{ae} for Eskisehir is given as 5 with its areal extent of 34208 hectares (table 6.2 and figure 6.3b).

Table 6.2. The distribution of areal extents for earthquake

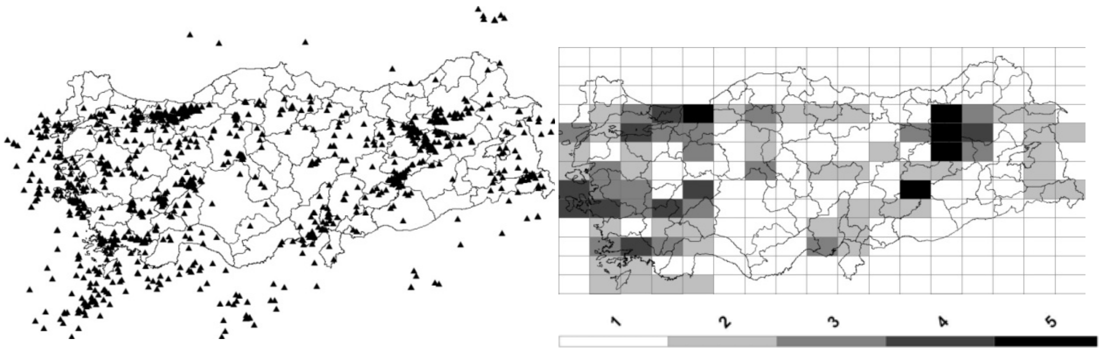
Classification	# of settlements	%	uae
726 < area size ≤ 4516	**90**	**0.27**	**1**
4516 < area size ≤ 5089	**22**	**0.06**	**2**
5089 < area size ≤ 8880	**108**	**0.32**	**3**
8880 < area size ≤ 33940	**98**	**0.29**	**4**
33940 < area size ≤ 199632	**21**	**0.06**	**5**



(a) (b)

Figure 6.3. (a) Values of the (a) p and (b) uae attributes for Eskisehir and nearby areas

To determine the frequency of earthquakes in Eskisehir and compare this to the computed value of f, the earthquake database of the General Directorate of Disaster Affairs Earthquake Research Department (DAD, 2009) was used to identify the earthquakes that occurred between 1991 and 2009 with magnitudes greater than 4 on the Richter scale. An earthquake point map (figure 6.4a) was generated using this dataset. The generated point map was based on a Quadrant analysis, the simplest method to represent the first order density of data. Relative frequency comparison of the settlements was used to represent these first order density in this study. The basic logic behind the method is counting the points in a grid cell and mapping the count results relative to the other grid cells. The generated frequency map values were then categorised into five classes, numbered 1-5 (figure 6.4b), where 5 indicates those areas of Turkey with the highest frequency of earthquakes. According to the results, Eskisehir's *f* value is found to be 3.



(a) **(b)**

Figure 6.4. (a) The earthquake positions between 1991-2009 with magnitudes greater than 4 on the Richter scale (b) Frequency distribution of earthquakes across Turkey

Apart from *f*, the other temporal hazard attributes, namely *d* and s_o, were derived from empirical comparisons. Compared to other natural hazards, earthquakes can be classified as a hazard with a short duration (table 6.3). Therefore, the *d* attribute is given a value of 1 and a fast speed of onset and the s_o attribute is given a value of 5 on the scale of 1-5.

Table 6.3. The proposed s_o and d parameters for different natural hazards

Disaster	Speed of onset (immediate precursor period)	Duration (impact)
Earthquake	**Seconds**	**Seconds**
River flood	**15 hours**	**36 hours**
Dam breaching	**Minutes**	**Hours**
Tsunami	**Couple of hours (it depends on the depth of water and distance V=$\sqrt[2]{g.h}$)**	**Couple of hours (for well-drained lands)**
Forest fire	**Hours**	**Hours - days**
Tornado	**Minutes**	**Minutes**
Hurricane	**Several Days**	**Several Hours**
Drought	**Gradual (moths - years)**	**Months - Years**
Soil and water pollution	**Gradual (depends on the amount of chemical disposal)**	**Days – Months**

The calculation of the spatial dispersion constitutes the last step in the process of defining the complete model attributes. The s_d attribute is related to the spatial distribution pattern of the hazard. The earthquake dataset of the General Directorate of Disaster Affairs Earthquake Research Department (DAD, 2009) was used again to identify the spatial dispersion map (figure 6.5) of earthquakes. Kernel density function (obtained using ESRI ArcGIS software, as in the *f* calculation) was used, with the magnitudes of the earthquakes constituting the weights. Eskisehir is located in the second greatest earthquake occurrence zone, so the attribute value of s_d is 4.

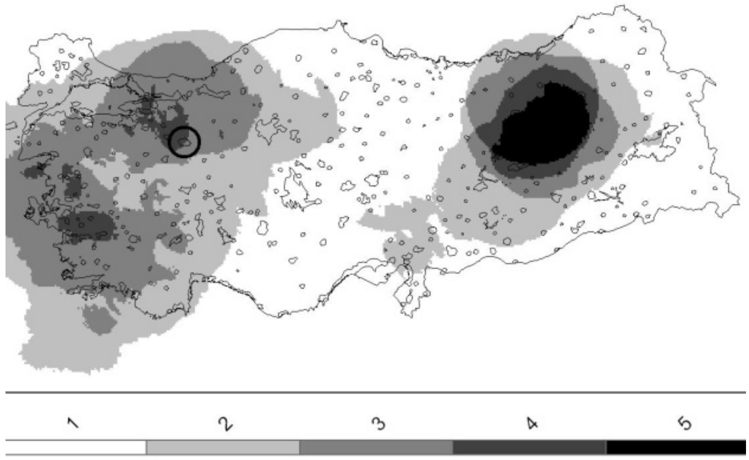


Figure 6.5. Earthquake spatial dispersion classification

Table 6.4 represents the attribute values for the Eskisehir Earthquake case study. The indoor penetration parameter *i* was assigned a value of 0, for there is no involment of hazardous materials into the built environment during earthquakes. The decision rule was applied using these values to determine the level of detail needed for the urban model.

Table 6.4. Eskisehir earthquake attributes

Criteria	U			H			
Subcriteria				H_t		H_s	
Attribute	d_s	u_{ae}	p	f	d	s_o	s_d	i
Value	4	5	2	3	1	5	4	0

$$I_p = [(((4 + 5 + 2) / 3) \times (((3 + 1 + 5) / 3) + 4) / 2)] = 12.83 \quad (12)$$

Entering these attribute values into equation (5):

$$I_{pnorm} = ((12.83 - 25) / (0 - 25)) \times 4)_{round} = (1.95)_{round} = 2 \quad (13)$$

and normalizing the calculated value of I_v using equation (12) yields:

$$D = 2 + (0/2) = 2 \tag{14}$$

The result of the decision rule is that the detail level (D) of the urban model required for this specific type of disaster and this particular city must be 2. According to the proposed LoD hierarch definition, LoD2 requires that building objects show differentiated roof structures and textures, and vegetation objects may be represented.

6.1.3.3 Phase III - Needs Assessment

After defining the model objects representation as LoD2, figure 6.6 represents the results of the representation requirements analysis for the Eskisehir earthquake application. Letters in roman type denote object representations while italic letters denote initial data types in figure 6.6.

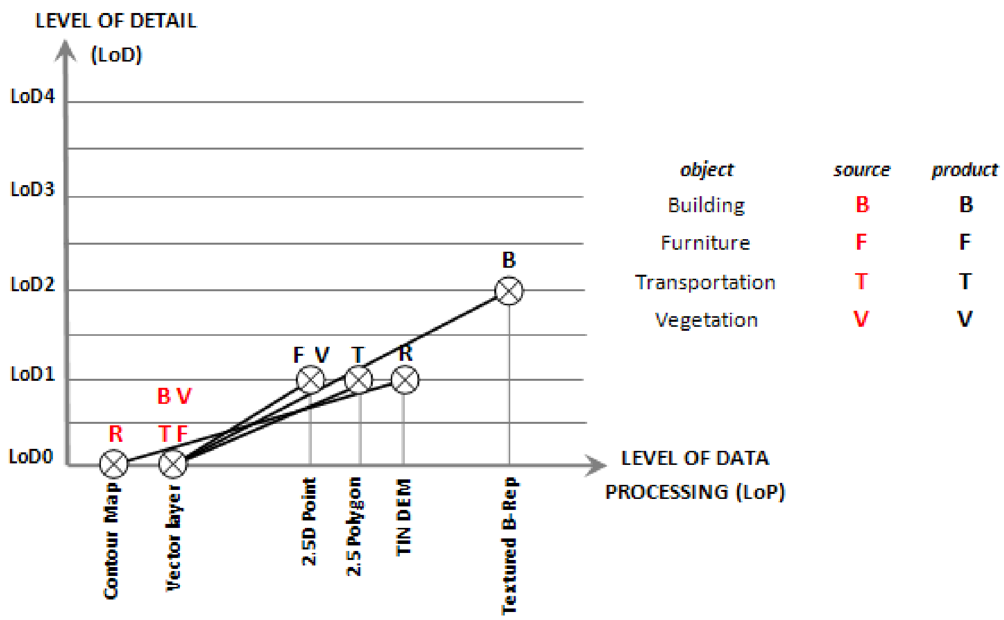


Figure 6.6. The cross-section of framework for an earthquake case

The available data for urban modeling are as follows:

Vector street and building footprint layers obtained from the Eskisehir Municipality Digital City Information System, and 1/25000 digital contour maps. To construct building objects, façade images and building height data are needed, which are collected by a field survey. Process steps to develop an urban model involve 2.5D DEM generation from digital contour maps, the generation of LoD2 buildings by using building height information and ground images, draping of city furniture, tree points, road data and building models with a terrain model, and relating tabular index data (in this case hazard characteristic medium) to the building objects.

6.1.4 Generation of the 3D Urban Model

After the object representation definitions are completed with the use of the proposed framework, the generation of the urban virtual environment stands as the last issue to be handled. A recursive process of development of the 3D urban model is adopted in the Eskisehir application. This process has two stages. The studies in the first stage cover those works that are completed before the technical interview with the user group. In second stage, the integration ways of CAD and GIS modeling functions are searched in the light of the user group feedbacks for a new pilot area that is also determined in that user interview.

In the first stage, office studies were conducted concerning 3D urban modeling theories. During the first stage, mainly two different studies were carried out to find the pros and cons of various 3D modeling environments. These studies are modeling in the CAD environment and modeling in the GIS environment. The first pilot area was selected within the Eskisehir metropolitan area. More precisely, Cumhuriye neighborhood in the central business district of Eskisehir (figure 6.7), with a population of 4113 according to the 2000 census, was selected. There are 434 buildings in the neighborhood.

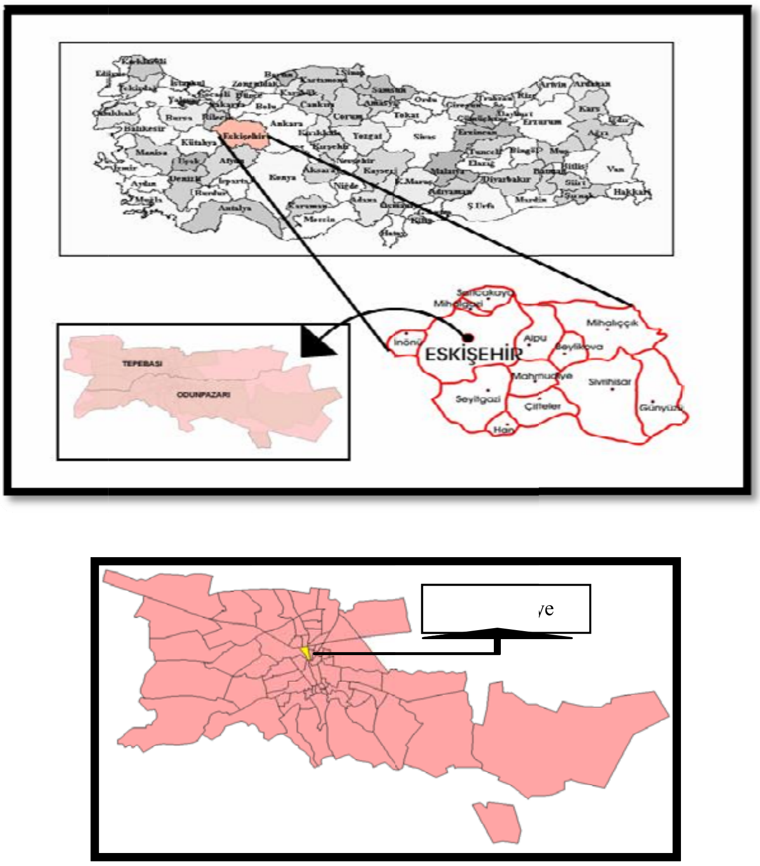


Figure 6.7. Cumhuriye neighborhood at Eskisehir

CAD modeling work steps

3D urban models generated by using the CAD modeling method are described in the framework analysis of the representation requirement section. In this section, the applications of vulnerability visualization are presented. The visualization of the earthquake vulnerability indexes of the buildings, which is the main aim of 3D urban model generation, is fulfilled by index tables in the CAD environment. Two different alternatives for index table visualization are tested.

- Dropping façade
- Transparent change

In the first alternative, the index table of each building can be seen with dropping building façade in the created visualization. When passing by a building, façade image drops and the index results are seen on the index table. Façade images are raised after passing by the building (figure 6.8).

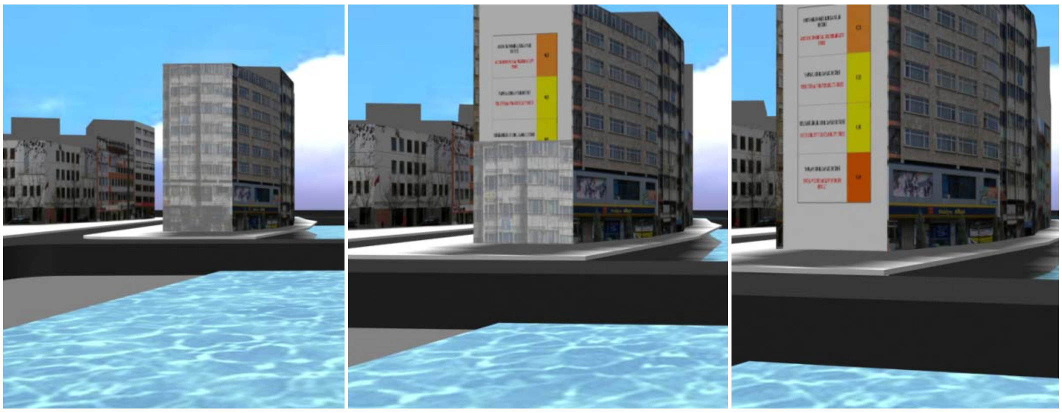


Figure 6.8. The visualization of various vulnerabilities in the 3D city model

In the second alternative, instead of dropping façades, transparent façade change is used to visualize the vulnerability index values. After passing the related building, façade image transparency value turns into its initial state (figure 6.9).

Figure 6.9. The visualization of various vulnerabilities in the 3D city model

GIS modeling work steps

GIS-based 3D modeling is the second alternative modeling method. Two methods are compared after two separate applications. GIS intrinsically use tabular and geographic data. This characteristic is the main superiority of GIS environment over CAD. The desired result from GIS/RS 3D model was effective geographical querying and visualization of the related data. Each building's vulnerability index result can be queried on the created model at floor level. There are two main parts of the GIS modeling.

- Raster-based operations; the creation of reference image map from stereo satellite images and the creation of digital elevation model (DEM)
- Vector-based operations; 3D layer operations

Raster-Based Operations

DEM generation is the first raster-based operation. A DEM is defined as a file or a database containing elevation points over a contiguous area (Manual of Photogrammetry, 2004). The needed field height data for the DEM generation can be obtained from point, line or polygonal vector height maps or stereo satellite/aerial images. The generated DEM is used for base heights for the 3D city model. Besides, DEM is also used for the photogrammetric rectification of satellite images. There are 21 pieces of elevation maps covering all the Eskisehir City. First, all these maps were combined and the pilot area and the surrounding region were cropped to generate DEM (figure 6.10).

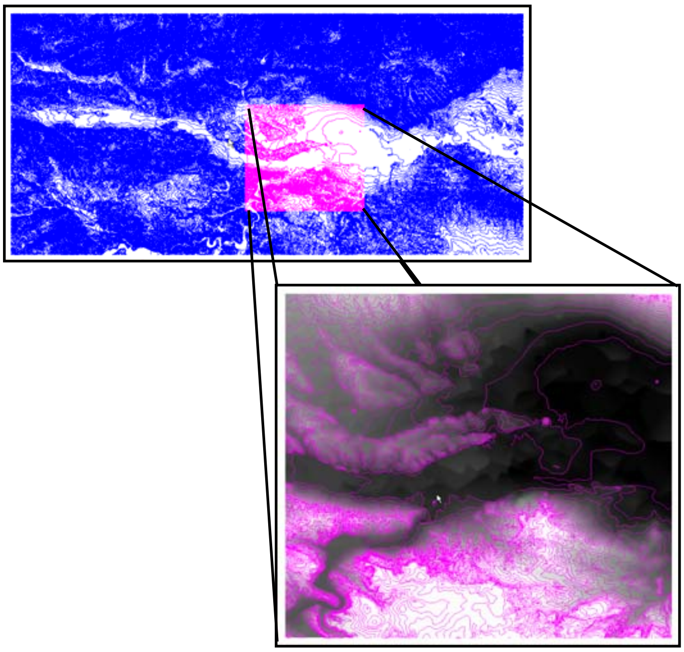


Figure 6.10. Study area contour map and the generated DEM

The next step of the raster-based operations part of the GIS modeling studies is the geometric correction of satellite images and orthographic correction of this geometrically corrected image by using the previously generated DEM.

Coarse satellite images may have geometric, atmospheric, radiometric and angular distortions. Apart from geometric and angular distortions, other distortions are rectified at the satellite ground receiver stations. In order to fit vector GIS layers and reference image, images have to be rectified in advance. To rectify satellite images, image to map image rectification algorithm is applied. Three different functions of mathematical transformation were experimented. These transformation functions are;

- Polynomial
- Rational
- Satellite model

Satellite model gave the most appropriate results. The vector road layer obtained from the municipality was used at this stage. Ground Control Points (GCP) collected from the road layer for image registration and the results of the registration were checked by using the same layer. Rational and satellite model result can be seen in figure 6.11.

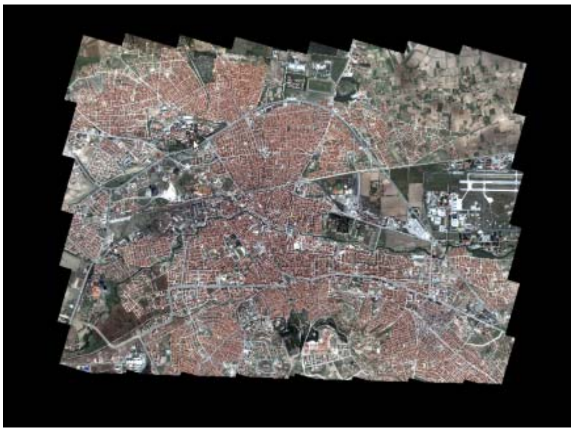
Figure 6.11. Rational function result at left hand side and satellite model result at right hand side

There were 42 GCPs collected for image registration. The overall root mean square error (RMSE) values computed for GCPs using satellite model were 0.47 pixels at X axis and 0.63 pixels at Y axis.

Another raster-based operation that was carried out is Image Mosaicing. Two pairs of Ikonos images cover the study area. After creating the georeferenced orthophotos, left and right stereo pairs are mosaiced to generate a whole reference image. The nadir images of the left and right pairs are used for mosaicing. The mosaiced result image is given in figure 6.12. The image and DEM results constitute the basis of vector layer operations (figure 6.13).

(a)

(b)



(c)

Figure 6.12. (a) Left image (b) right image and (c) mosaic result

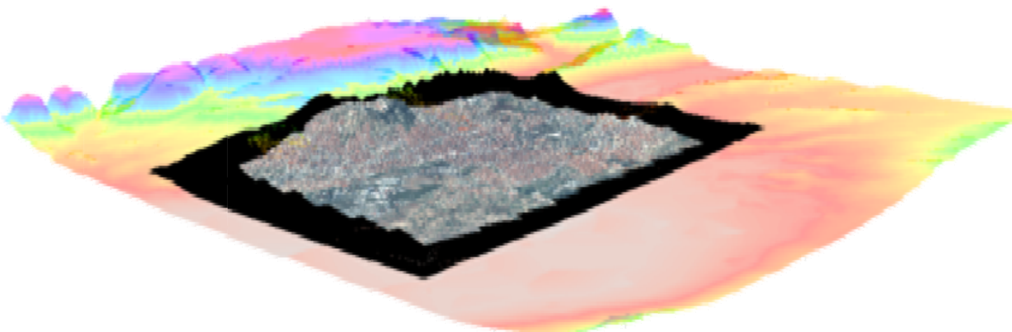


Figure 6.13. Mosaiced orthoimage on the generated DEM

Vector-Based Operations

The main intention for the GIS modeling part of the study was the thematic visualization of the disaster vulnerability condition of the buildings on the generated 3D model. The generated DEM model and the ortho satellite images are used as reference for 2D vector building footprints acquired from the Eskisehir Municipality (figure 6.14).

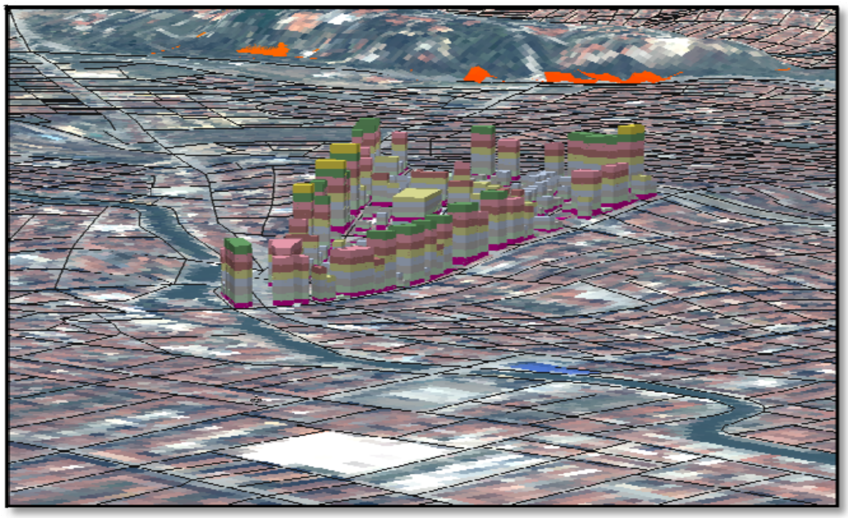


Figure 6.14. The 3D perspective view of the generated 3D GIS/RS city model (the same colours represents the same floors in each building). The merged ortho satellite image and the other vector layers on DEM

Both environments have pros and cons. GIS intrinsically use tabular and geographic data, which is the main superiority of GIS environment over CAD. On the other hand, CAD environment provides more sophisticated visualization properties, which improves decision maker's perception. In order to take advantages of both environments, they should be integrated.

The pilot area, determined for the second stage modeling studies, is a part of the city centre, including some portion of the Akcaglan, Akcami and Pasa neighborhoods of Odunpazari district and has various kinds of urban textures including low-rise, historic and high-rise buildings. There are nearly 400 buildings in the application area (figure 6.15).

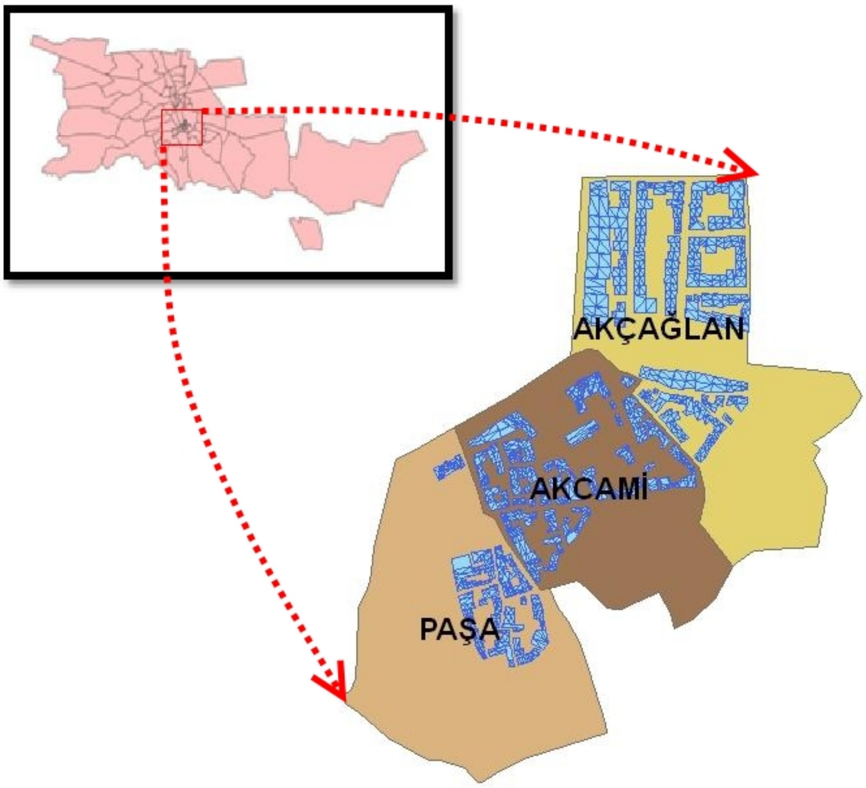


Figure 6.15. The study area for the second stage modeling studies

For the second phase of the Eskisehir application, the CAD software of Google SketchUp is used. The problem of GIS and CAD integration encountered in the first phase modeling studies was solved by using ArcGIS for SketchUp 6 plug-in. Thanks to this plug-in, 2D GIS data constitute a base for 3D models with high detailed textures. Moreover, further analysis can be probable by exporting Sketchup modeling results to ArcGIS 3D Analyst extension. The plug-in is compatible with only SketchUp 6 and ArcGIS 9.2. The selected 2D building footprints can be exported by using the plug-in. During this process, building elevation and height information are used to create untextured B-reps of the target building. Texture mapping and roof modeling are two consecutive works requiring these input data. These work steps are applied for each building object individually, because SketchUp exports them as Multipatch features, and these processes need to be done individually to identify each building feature as an object (figure 6.16).

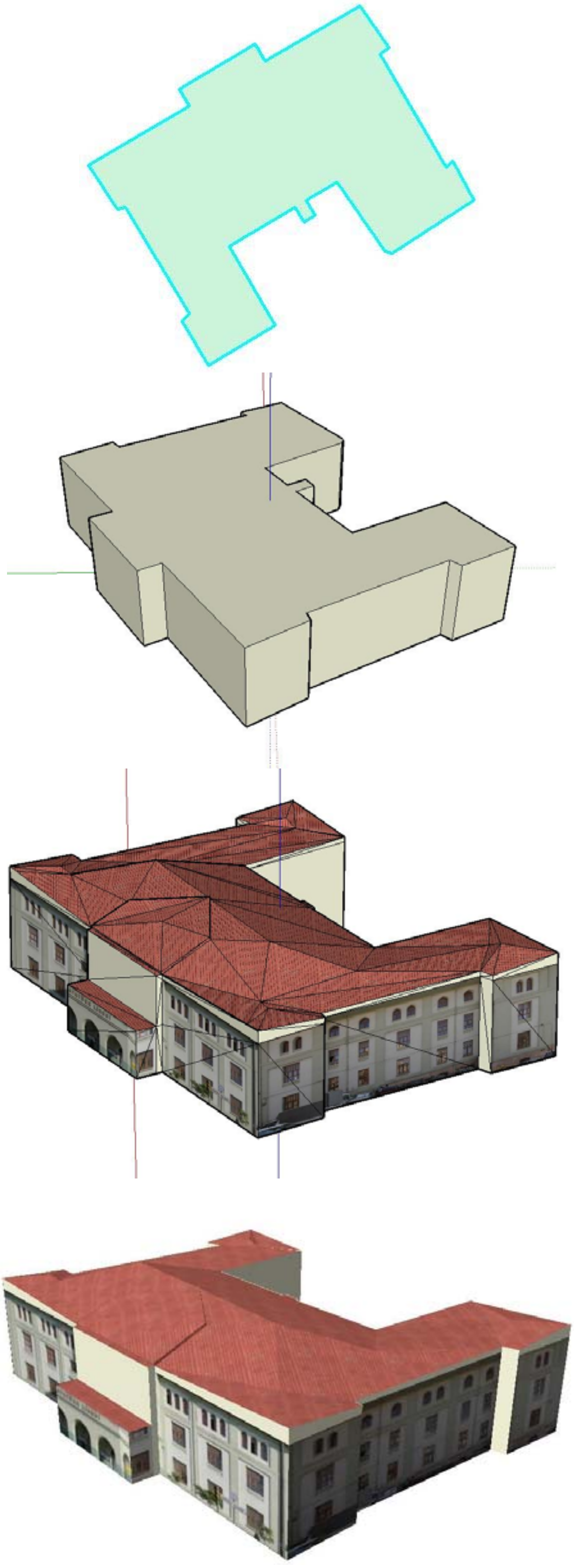
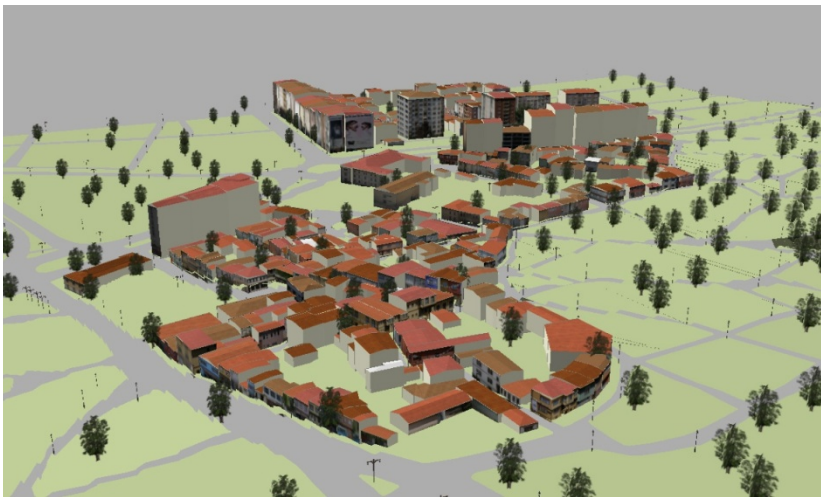


Figure 6.16. 3D Building modeling process

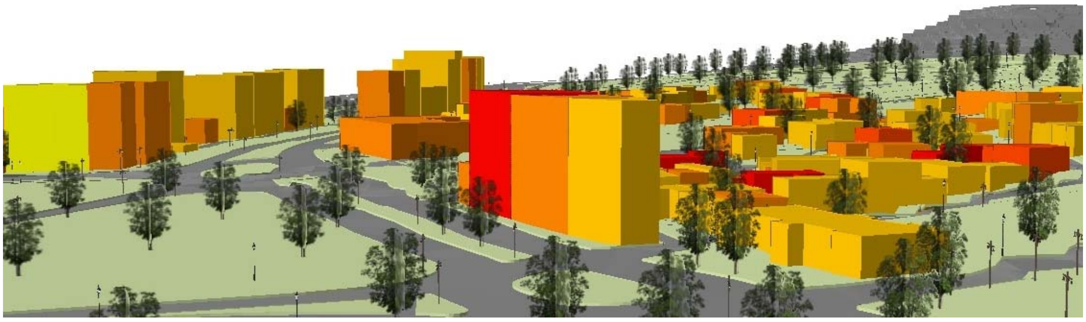
SketchUp modeling outputs are initially georeferenced so they do not need one more georeferencing. In the GIS environment, firstly one building layer is generated using these single building objects, and then the generated 3D building model layer is treated as another GIS layer (figure 6.17).



(a)

(b)

(c)



(d)

Figure 6.17. (a) (b) General views from the 3D city model generated for Eskisehir earthquake case (c) Textured and (d) thematic views from the 3D city model generated for an earthquake case

The created urban model has the advantages of both CAD and GIS environments. The model enables querying tabular data and any other GIS analysis function properties (figure 6.18). Moreover, advanced visualization capabilities are added by CAD integration.

Figure 6.18. The example of building tabular data querying

6.2 Tsunami Implementation

6.2.1 Background

The other illustration case is the Fethiye tsunami inundation visualization. The main aim of the tsunami case is to carry out 3D dynamic inundation visualization for the city centre on the shoreline. Fethiye is a town of Mugla Province in the Aegean region of Turkey, with about 68,000 inhabitants. It is one of Turkey's well-known tourist centres. In the Fethiye tsunami case, 3D dynamic inundation visualization of computed tsunami propagation and coastal amplifications for worst-case rupture were performed to simulate and understand the impact of tsunami specifically on Fethiye Bay on the Southern coast of Turkey.

Numerous earthquakes and associated tsunamis occurred throughout the history in the Mediterranean Sea. These are precursors to similar events in the future (Altinok et al., 2011). The fault zones around the eastern Mediterranean basin are Hellenic Arc, North Anatolian Fault Zone, East Anatolian Fault Zone, Cyprus Arc, and Dead Sea Fault. At the centre of the Aegean Sea, there is a series of volcanic systems almost parallel to the trench forming the internal arc (Milos, Antimilos, Antiparos, Santorini, Christiana, Colombus, Kos, Yali, Nisiros and others). Since it is a part of the city centre, the pilot area contains the main economic activity space of the urban area (Ozer et al., 2009).

The GIS-based application of 3D inundation visualization of Fethiye tsunami has two main phases. First, Numerical Tsunami simulation is completed in the NAMI DANCE, which is a computational tool, used for the generation of tsunami wave, and at the second phase GIS-based 3D visualization with generated tsunami waves and urban environment is prepared.

Numerical simulations is one of the major research area. The literature on numerical tsunami simulation can be found from Tinti et al. (1994) and Yalciner et al. (2002).

Some numerical tsunami simulation software allows the user to integrate geo-spatial data with numerical tsunami wave simulation. These are TSUNAMI CEA/DASE, TsunamiClaw, Coulwave, COMCOT, UBO-TSUFD&UBO-TSUFD-VB, UBO-TSUFE, TSUNAMI-SKREDP, 1HD, H2D DPWAVES, GLOBOUSS, C3 Tsunami Model, MOST, TUNAMI N1, N2, N3 and lastly NAMI DANCE. In software literature, three types of software integration can be found. These are *integration with only data exchange*, *common user interface* and lastly the most ideal one, *full integration*. According to this classification, the integration of numerical simulation software (NAMI DANCE) with GIS software (ESRI ArcGIS 9.2) can be classified as integration with *only data exchange*. In the tsunami inundation case, the integration of these is needed during the phases of wave simulation and the interpretation of results in GIS environment.

Tsunamigenic earthquake data, sea floor and land topography are the main inputs of NAMI DANCE. These numerical wave simulation inputs are organized from different data sources in GIS environment. In the same way, the results of the numerical tsunami simulations are transferred to the GIS environment for interpretation and visualization.

6.2.2 Study area

The surface area of Fethiye is about 2686.411 km^2 and has a 167 km coastline. There are 18 islands in the district. The most important ones are Sovalye, Kızılada, Katrancı, Tersane, Domuz, Yassica, Gemile, Ayanikola, and Karacaören islands. 72% of the district area is covered by forest and scrub land. According to the 2009 census, the population of the city is 72003 (Turkish Statistical Institute). The local administrative structure of the city consists of 16 neighborhoods (figure 6.19).

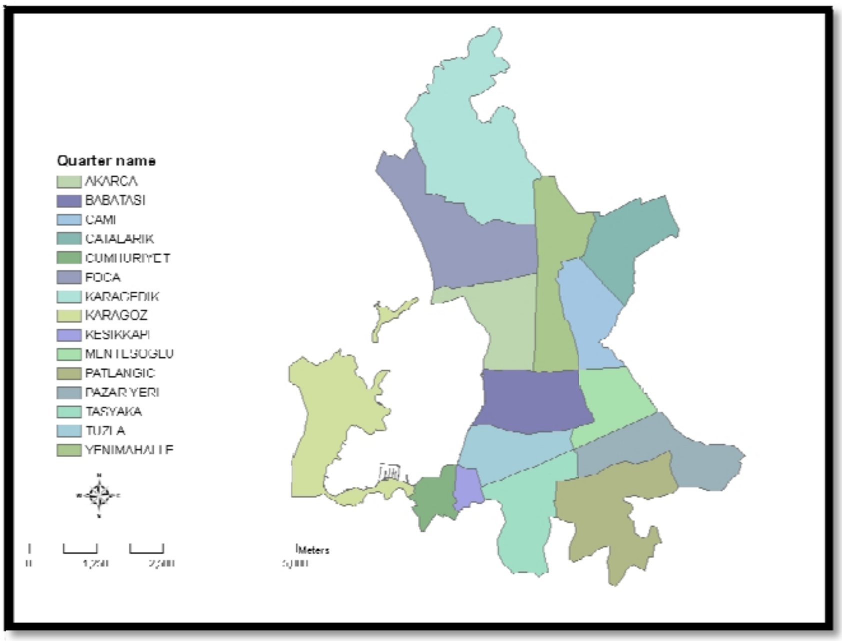


Figure 6.19. The neighborhood borders of the Fethiye City

Level II local scale modeling study was conducted over a pilot area, which contains 1774 buildings within the neighborhoods Kesikkapi, Cumhuriyet, Tuzla, Babatasi and Karagoz (figure 6.20). The study area is a part of the central business district (CBD) of the Fethiye City (figure 6.21).

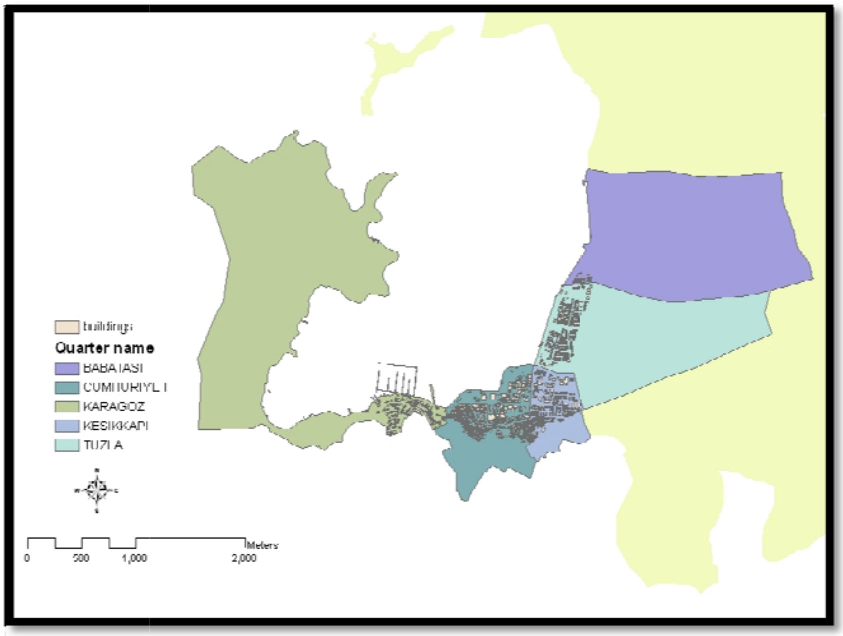


Figure 6.20. Tsunami implementation area with related building objects and neighborhood borders

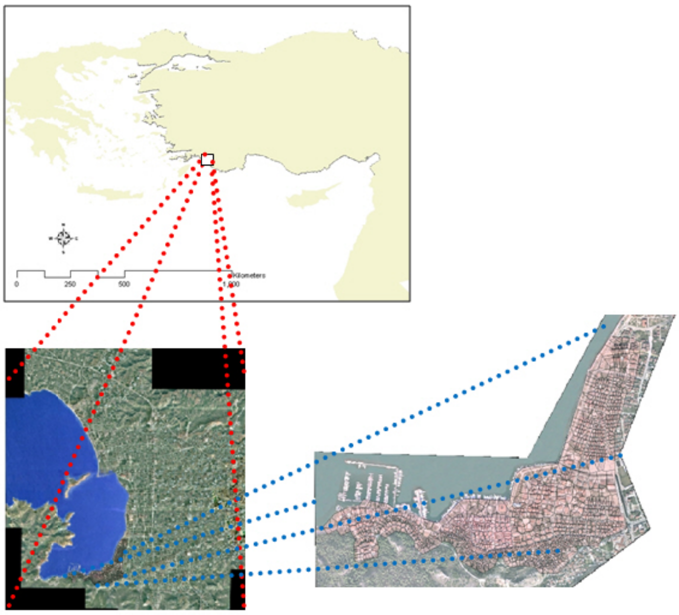


Figure 6.21. Tsunami inundation case study area, Fethiye City CBD

6.2.3 Application of the Framework

6.2.3.1 Phase I - Definition of visualization components

The user component of these visualizations is academia; they are experts in the tsunami field but non-GIS experts. In general, they need relatively realistic run-up visualizations. The basic elements at risk are considered to be the buildings. The model objects defined to construct a realistic visualization environment are;

- Buildings
- Terrain
- The tsunami waves

6.2.3.2 Phase II - Object representation

In the 3D tsunami inundation case, a two-level object evaluation process was applied. At the first level, the tsunami hazard situation of the Fethiye City was compared with all the settlements with the scale of the country by using regional-scale tsunami assesssment. At the second level of the evaluation, research focused on the shoreline part of the city centre by using local-scale tsunami assessment study. With the outputs of the regional-scale tsunami assessment, a detailed work can be possible on local scale.

Level I (general scale) object evaluation

As it was mentioned in the previous part, in the tsunami inundation case some sort of software integration is needed between two environments (GIS and numerical tsunami simulation). Data input, manipulations and output operations of both environments are explained in Appendix A. Regional-scale and local-scale numerical tsunami simulation results formed the input for the GIS environment at three different places (figure 6.22). These places are Level I, Level II decision rule applications, and lastly, the generation of water object as hazard medium during the construction stage of the 3D urban model.

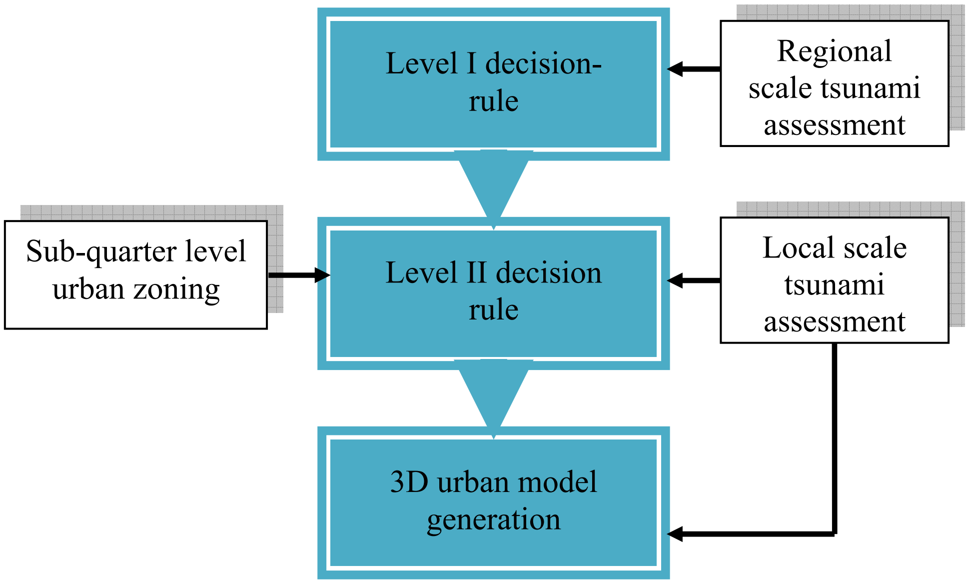


Figure 6.22. Fethiye Tsunami application flowcharts

In the first level tsunami studies, the evaluation of all Turkish coasts was carried out to come up with a general view and to compare Fethiye's situation with this general view.

Regional-Scale Tsunami Assessment

A probabilistic approach was applied to find the tsunami hazard zones in Turkey. According to the tsunami cataloging studies, 69 tsunamigenic earthquakes occurred in Turkey and other close regions (figure 6.23). In this approach, among all the defined faults, 35 of them are assumed as source faults, which presumably cause tsunamis for the Aegean and Mediterranean coasts of Turkey. The choice of source faults was performed with expert opinion.

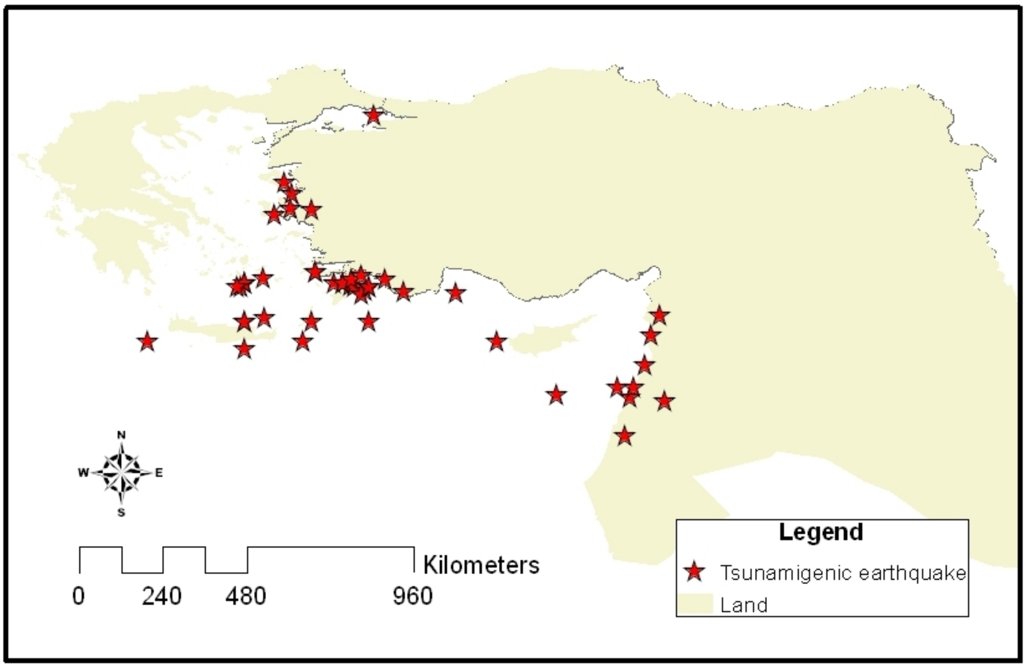


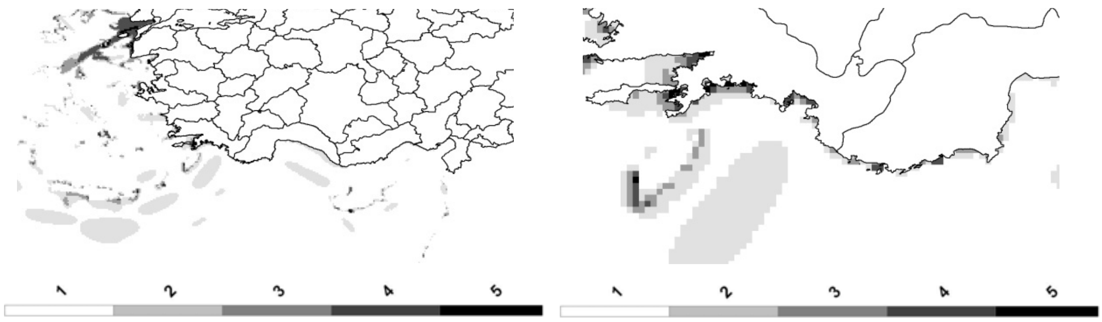
Figure 6.23. Tsunamigenic earthquakes occurred in the Black Sea and the Mediterranean

For each source fault, a numerical tsunami simulation was computed. This computation was performed through a three-phase study. The first phase is related with the *computation of the tsunami source parameters*. These parameters are essential for numerical simulation, and computed from the estimated rupture characteristics. In the second phase, the *determination of study domain* for numerical modeling of tsunami is completed. Sea floor and land topography (by using GEBCO, Contour and GPS data), spatial grid size of each domain must be obtained. The reliability of results solely depends on the accuracy of these input data. Moreover, the last phase is *simulation and computation of all necessary tsunami parameters*. Height data are used for the propagation of tsunamis in the open sea and their coastal amplification and run-up at shallower regions and on land. GEBCO, contour and GPS data are combined to achieve a reliable sea floor and land topography. The aggregated data is in point data format and each point below sea level is given positive values while points above sea level are given negative values.

The outputs of numerical simulation are in *grd* format. In order to use these outputs in GIS environment, a series of conversions must be performed. These conversions are first *grd* to *dat*, *dat* to *txt* and lastly *txt* to *shp*. All these conversion steps are completed for all 35 different numerical simulation runs. At the end of the conversion steps, the obtained *shp* files are vector files containing point details. Those files contain water height information for each point in the input field. To acquire continuous water height surfaces from these discrete data, inverse distance weighting (IDW) interpolation method was applied in ArcGIS 9.2. Finally, two different weight parameters were generated by using these simulation results of all 35 sources. These parameters were total tsunami height and the number of tsunami cases for each pixel.

Level I Decision rule

A final tsunami hazard map (figure 6.24a) was generated with the summation of two standardized inputs for the Aegean and the Mediterranean, which surround the western and southern coasts of Turkey. The coasts in Fethiye district (figure 6.24b) were in the third severe hazard zone on the scale of 1-5, hence, d_s was assigned a value of 3.



(a) **(b)**

Figure 6.24. (a) The Aegean and the Mediterranean tsunami hazard zones of Turkey, (b) Fethiye and surroundings hazard zones for disaster susceptibility (d_s) attribute

The evaluation of the attributes *p* and u_{ae} was conducted for 339 settlements in Turkey like in the Eskisehir case. Again, the relation between areal extent and the needs of the model detail is not linear; therefore, the areal extent adds complexity to the urban system, necessitating a more detailed modeling approach. Fethiye, with a population density of 2.62 per/ha, is classified as $p = 5$ (table 6.5 and figure 6.25a). In this approach, high population density values map to low *p* attribute values, indicating that they require intensive modeling approaches.

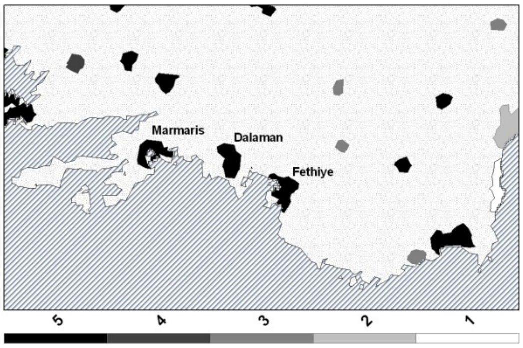
Table 6.5. The distribution of population density values for tsunami

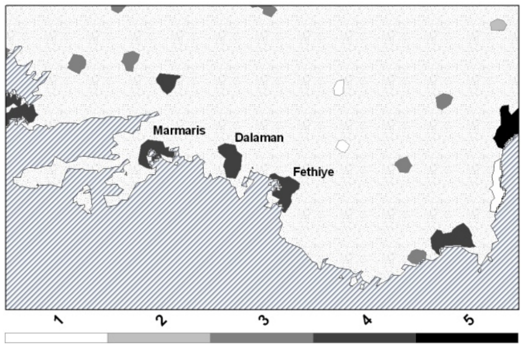
Classification	# of settlements	%	p
0.65 < pop_dens ≤ 4.47	**108**	**0.31**	**5**
4.47 < pop_dens ≤ 5.30	**46**	**0.14**	**4**
5.30 < pop_dens ≤ 9.12	**119**	**0.35**	**3**
9.12 < pop_dens ≤ 26.74	**64**	**0.19**	**2**
26.74 < pop_dens ≤108.05	**2**	**0.01**	**1**

The value of u_{ae} for Fethiye is 4 with its areal extent of 19345 hectares (table 6.6 and figure 6.25b).

Table 6.6. The distribution of areal extents for tsunami

Classification	# of settlements	%	u_{ae}
726 < area size ≤ 4516	**90**	**0.27**	**1**
4516 < area size ≤ 5089	**22**	**0.06**	**2**
5089 < area size ≤ 8880	**108**	**0.32**	**3**
8880 < area size ≤ 33940	**98**	**0.29**	**4**
33940 < area size ≤ 199632	**21**	**0.06**	**5**

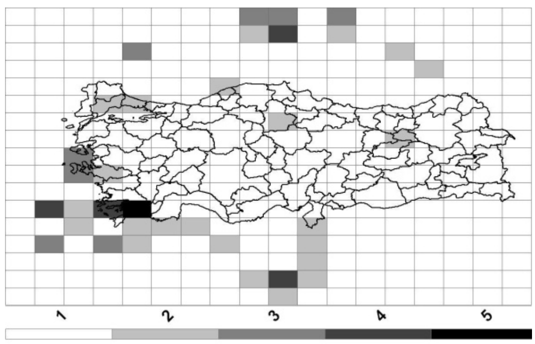




(a) (b)

Figure 6.25. The values of the p (a) and uae (b) attributes for Fethiye and nearby areas

Tsunamis observed on and near Turkish coasts are listed in Altinok et al. (2011). The coordinates of the listed records (figure 6.26a) were used to determine the relative frequency distribution of tsunamis. The generated point map constitutes the basis of the Quadrant analysis. The generated frequency map values were again categorised into five classes, numbered 1-5 (figure 6.26b). According to the results, The *f* value of Fethiye tsunami is 5.



(a) **(b)**

Figure 6.26. (a) Earthquakes, which caused tsunamis on the Turkish coast's (b) The relative frequency distribution of tsunamis across Turkey

The other temporal hazard attributes d and s_o was again derived from empirical comparisons. Compared to other natural hazards, tsunami can be classified as a hazard of medium duration and medium speed of onset (table 6.3). Therefore, the d and s_o attributes were both given values of 3 on the scale of 1-5.

Tsunami s_d map (figure 6.27) was generated using the same dataset, which was published by Altinok et al. (2011). Kernel density function (obtained using ESRI ArcGIS software, as in the f calculation) was applied. Fethiye is in the highest earthquake occurrence zone, so the attribute value of s_d is 5.

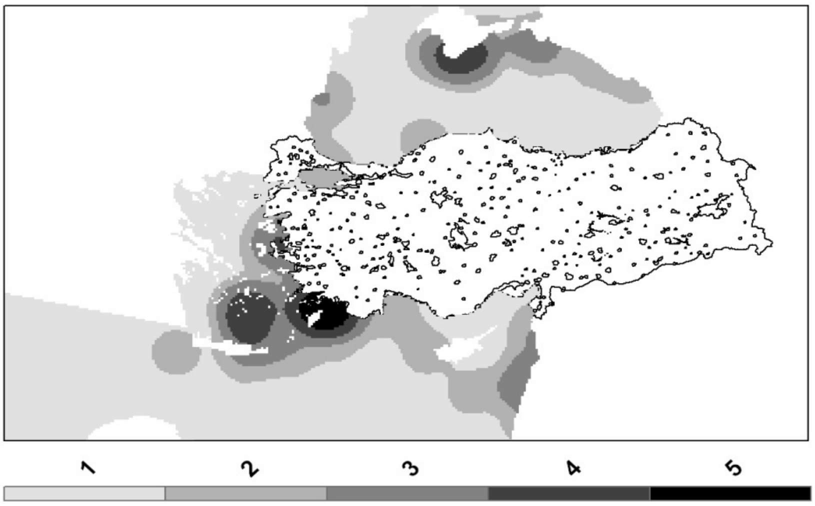


Figure 6.27. Tsunami s_d classification for Turkish coasts

Table 6.7 represents the attribute values for the Fethiye Tsunami case. The decision rule was applied using these values to determine the level of detail needed for the urban model.

Table 6.7. Fethiye tsunami Level I evaluation attributes

Criteria		**U**			**H**			
Subcriteria					H_t		H_s	
Attribute	d_s	u_{ae}	**p**	**f**	**d**	s_o	s_d	**i**
Value	**3**	**4**	**5**	**5**	**3**	**3**	**5**	**1**

$$I_p = [(((3 + 4 + 5) / 3) \times (((5 + 3 + 3) / 3) + 5) / 2)] = 17.33 \quad (15)$$

Entering these attribute values into equation (5):

$$I_{pnorm} = ((17.33 - 25) / (0 - 25)) \times 4)_{round} = (1.23)_{round} = 1 \quad (16)$$

and normalizing the calculated value of I_p using equation (16) yields:

$$D = 1 + (1/2) = 1.5 \quad (17)$$

The result of the decision rule is that the detail level (D) of the urban model (D) is required for this specific type of disaster, which is 1.5. Note that *i* take the value of 1 here, and the D value is with the half part, because there is an indoor penetration. This requires building objects in a simple box form and storey level indoor representation.

Level II (local-scale) object evaluation

After the general scale study, a local-scale tsunami modeling study was conducted to visualize the results of the impacts of most risky tsunami scenarios on built-up urban areas. At this scale, a sub-neighborhood level urban zoning approach was used to compare the impact of tsunami. This comparison is used for the LoD definition of 3D urban model, which is generated as a tool to communicate risk due to tsunami.

Local-Scale Tsunami Assessment

Detailed height information of sea and land topography and building height information appended to these constitute the main input of the numerical tsunami modeling. Three different source data were used to generate this input. One of them is the DEM acquired from "Korfez Haritacilik", a cartography company, which completed base map generation job for Fethiye and near surroundings. DEM generated with photogrammetric methods has 20 cm horizontal and vertical positional accuracy. Bathymetric measurements work, which was the second data source used to generate the input, was completed for a European Union (EU) funded project, namely Tsunami Risk and Assessment for European Region (TRANSFER) Project. Then, so as to generate the input data, which should be in sequential point entry format of the NAMI DANCE, continuous DEM (figure 6.28) and bathymetry data were converted to the point detail with regular points.

For local-scale tsunami modeling, which was the third data source used to generate input for numerical tsunami modeling, building objects were introduced to the other point mass. The building corner points entered were generated from the building polygon entries of the used 1/1000 base maps. Thus, constructing a tsunami model that takes into accounts the man-made structures as well as topography of the land and bathymetry can be possible. The obtained model results give detailed information for large-scale applications.

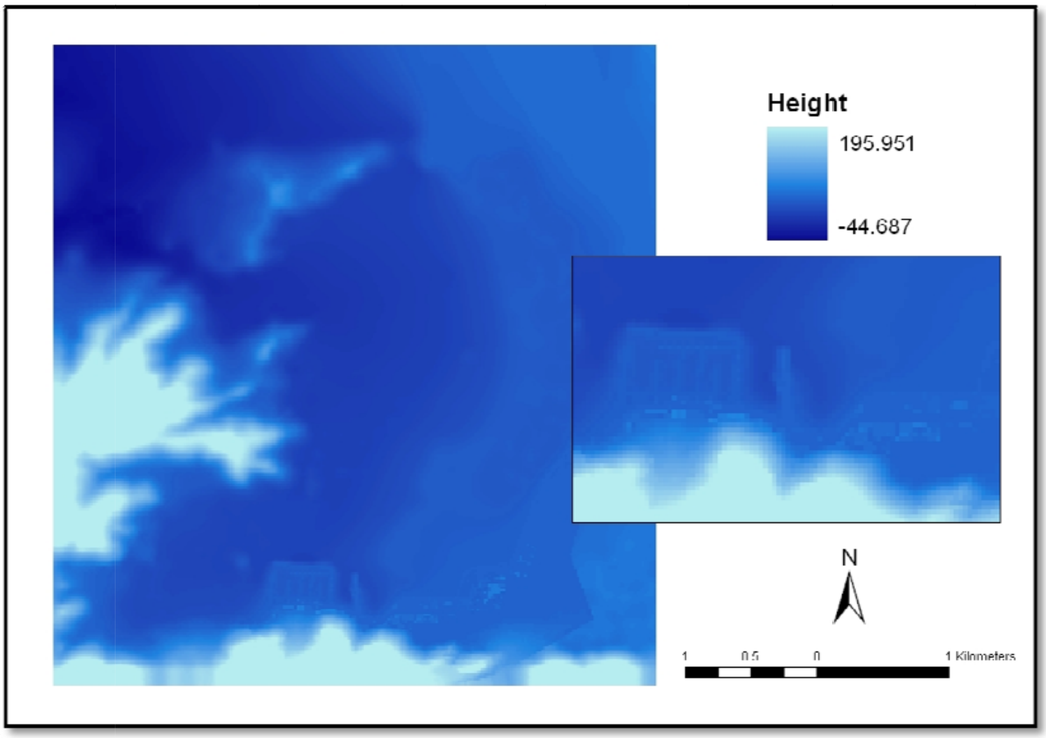


Figure 6.28. DEM of the main input of the numerical tsunami modeling

The generated earth surface data are used in an experimental numerical tsunami model, constructed with a source fault on Fethiye Bay. Other model parameters are;

- Grid size: 3m
- Simulation duration: for 30 minutes with 40 second interval
- Coordinate of point at centre: x= 29.11, y= 36.633
- Coordinate of point on major axis: x=29.113, y=36.638
- Length of major axis (meter): 1000
- Length of minor axis (meter): 450
- Amplitude at centre: 2
- Amplitude of leading wave (meter): - 2
- Width of leading wave (meter): 250

This scenario was studied to see the worst tsunami case in the CBD of the Fethiye city. The output of the numeric model is 45 grid file, which represents water height information, starting from t=0 to t=1800 (sec.). Post-tsunami modeling operations to convert and use the outputs in GIS environment are summarized in Appendix C. it can be said that there are two main usages of the model outputs. These are hazard medium in 3D urban modeling and hazard assessment measurement for decision rule application for level II.

Level II Decision rule

At this point, four different zonation results (figure 6.29), the generation method of which is described in object representation section (chapter 4), constituted the input for the local-scale urban object evaluation application. At the end of the decision rule applications, the LoD definitions of four different alternative approaches were jointly evaluated to come up with a final LoD definition for the whole application area.

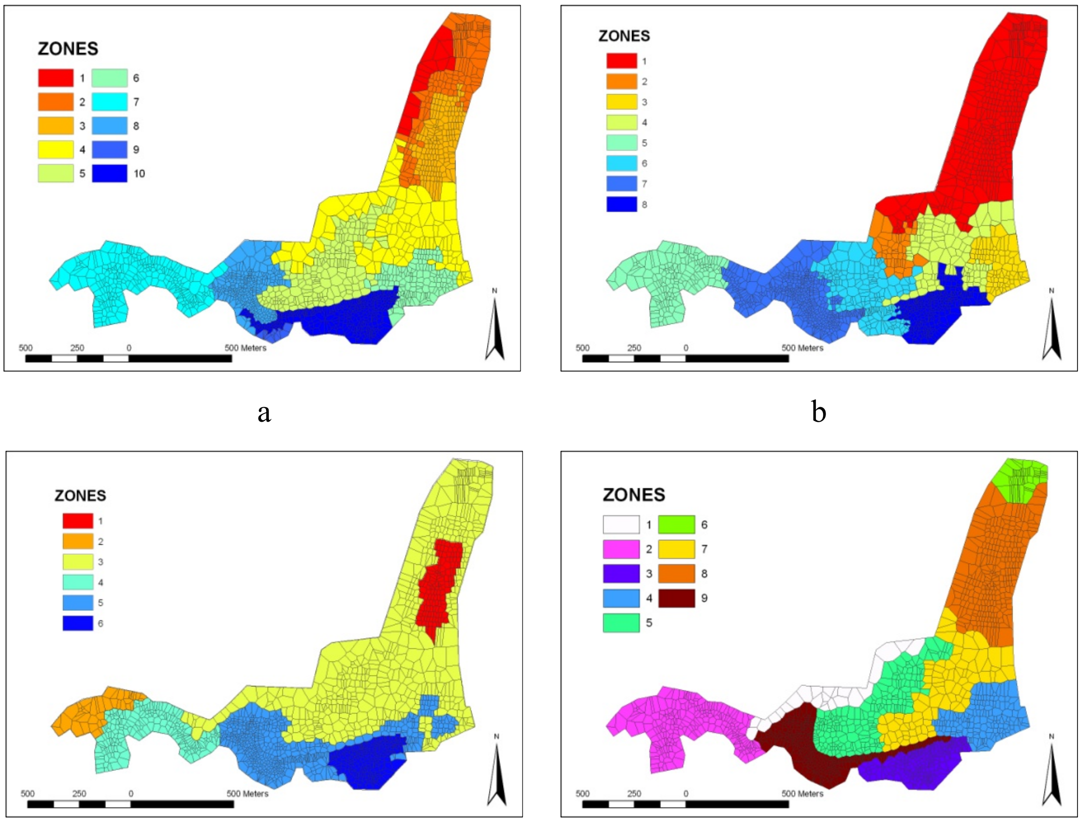


Figure 6.29. Four different zonation maps (a- density, b- geometry, c- kernel and d- expert opinion), input for the local-scale decision rule application

Similar to the Level I disaster evaluation, in Level II, disaster intensity evaluation was utilized to define the appropriate LoDs of each zone in the four different zonation approaches. Urban- and hazard-related spatial attributes were evaluated depending on the urban zone scale. Unlike the Level I evaluation, hazard- and urban-related attributes were evaluated based on the local attribute values on the defined urban zones, which have common urban pattern characteristics. According to the logic of this evaluation, an urban zone situated on a highly susceptible area with high population and structural density has the most detailed building object representation.

The calculation way of the decision rule attributes is as follows;

Disaster Susceptibility (d_s) attributes of each zone was calculated by dividing the mean elevation of the zone by the coastal length of the zone. This logic provides a zone with a low mean elevation and with a long coastal length, which is more susceptible than a zone with high mean elevation and short coastal length.

Urban Area Extent (u_{ae}) is a measure that represents the amount of the built-up area in the related zone. The built-up area measurement of each zone was calculated by using zonal statistics function of ArcGIS software.

Population Density (p) was also calculated by using ArcGIS zonal statistics function, the total population of each zone is the summation of all the populations of buildings located in the related zone. Building populations were calculated with an approach that considers the building base area, building height, average residence area and average household size. Building height value was obtained with the detection of the difference in building roof height and building ground height. Building roof heights are available in the land-use maps and ground heights are derived from the DEM.

The attributes of Frequency (f), Duration (d) and Speed of Onset (s_o) are the same for all zones. Consequently, in such a large-scale study, the temporal characteristics of the natural hazard, which has a large spatial spread like tsunami, could be assumed as constant. In this direction, general-scale attribute values were used and these values were the same for all zones.

Spatial Dispersion (s_d) attribute of each zone in the whole four zonation approach was calculated by using local-scale tsunami assessment study conducted on the Fethiye Bay. Likewise, the attribute of Indoor Penetration (i) was gathered from this tsunami assessment application.

Figure 6.30 represents the resultant LoDs of the building density approach. Each zone's LoD decision is derived from the decision rule application with the related attribute values given in table 6.8, table 6.9, table 6.10 , and table 6.11.

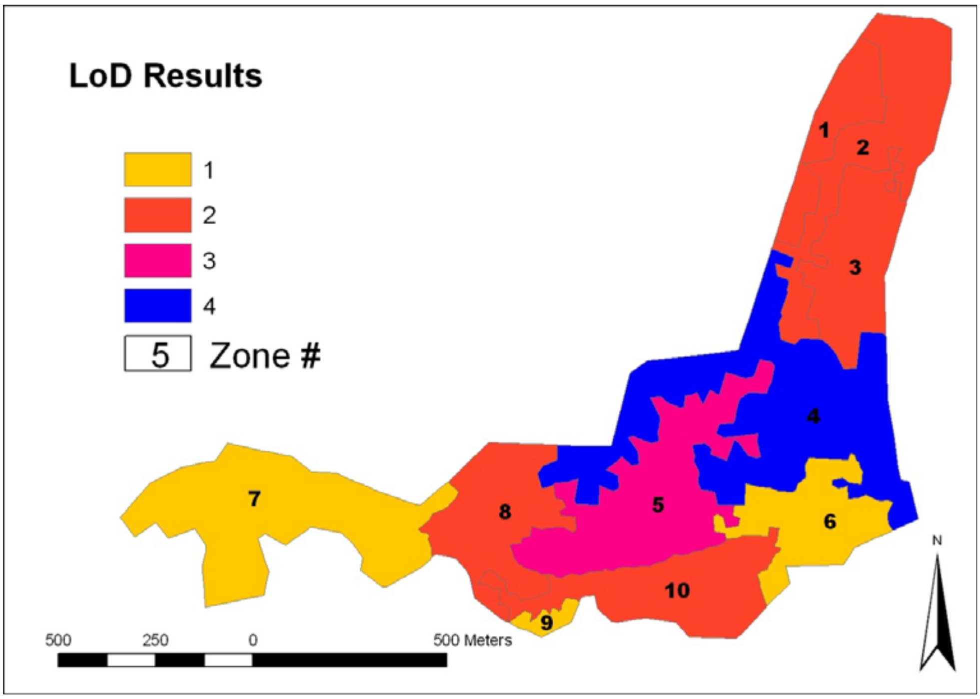


Figure 6.30. The defined LoDs of the building density approach

Table 6.8. Attribute d_s related measurements for building density approach

Zone #	Mean Elevation (m)	Coastal Length (m)	Coastal Length / Elevation
1	0.72	562	778.86
2	0.94	103	109.91
3	1.24	0	0.00
4	1.19	906	759.85
5	1.18	0	0.00
6	4.63	0	0.00
7	21.44	971	45.29
8	7.54	320	42.45
9	40.51	0	0.00
10	17.21	0	0.00

Table 6.9. Attribute u_{ae} related measurements for building density approach

Zone #	Base Area Summation (m^2)	Zone Area (m^2)	Structural Density
1	3663.21	48702.90	0.08
2	25473.55	110721.00	0.23
3	28263.90	85075.50	0.33
4	44400.54	232270.00	0.19
5	58533.23	145444.00	0.40
6	24416.71	77010.10	0.32
7	35572.29	171129.00	0.21
8	40728.32	92558.40	0.44
9	1527.89	8208.94	0.19
10	36188.55	97841.10	0.37

Table 6.10. Attribute p related measurements for building density approach

Zone #	Total Built Area (m^2)	Population (person)	Zone Area (m^2)	Population density (person / ha)
1	10495.56	467	48702.90	95.89
2	77775.92	3454	110721.00	311.96
3	91136.43	4060	85075.50	477.22
4	125916.23	5596	232270.00	240.93
5	170616.67	7588	145444.00	521.71
6	58932.95	2623	77010.10	340.61
7	89477.12	3969	171129.00	231.93
8	92873.87	4130	92558.40	446.21
9	2931.29	130	8208.94	158.36
10	74740.67	3328	97841.10	340.14

Table 6.11. Attribute s_d related measurements for building density approach

Zone #	Water Amount (m^3)
1	205.21
2	116.82
3	0.60
4	337.46
5	104.37
6	0.00
7	23.76
8	28.26
9	0.00
10	0.00

Figure 6.31 represents the resultant LoDs of the building geometry approach. Each zone's LoD decision is derived from the decision rule application with the related attribute values given in table 6.12, table 6.13, table 6.14, and table 6.15.

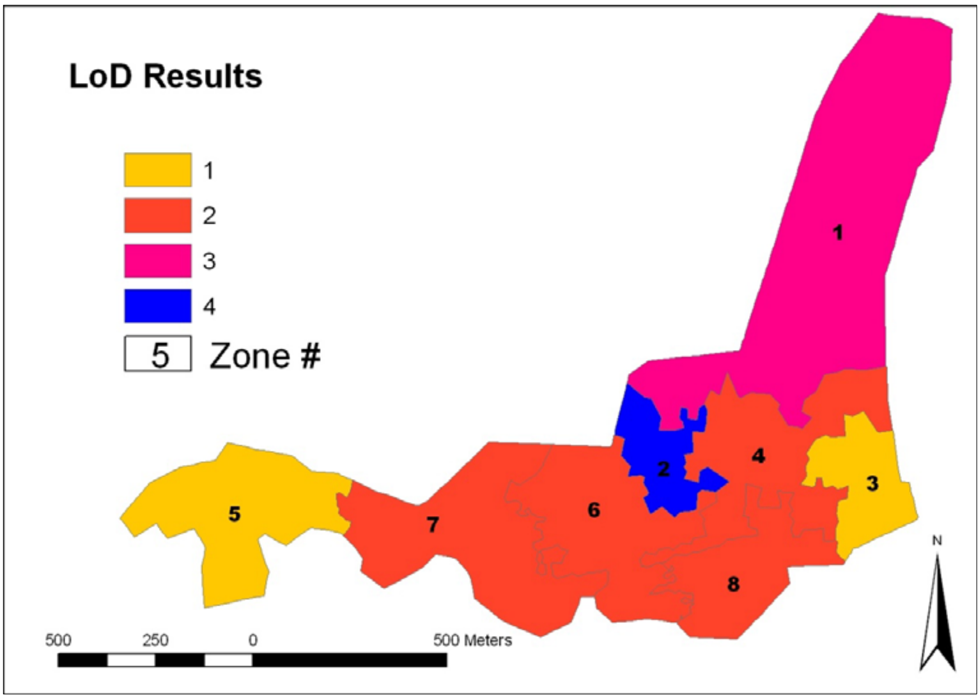


Figure 6.31. The defined LoDs of the building geometry approach

Table 6.12. Attribute d_s related measurements for building geometry approach

Zone #	Mean Elevation (m)	Coastal Length (m)	Coastal Length / Elevation
1	0.97	1263.00	1296.23
2	0.50	131.00	259.70
3	2.34	0.00	0.00
4	1.74	0.00	0.00
5	22.64	702.00	31.01
6	4.01	183.00	45.59
7	14.37	583.00	40.56
8	14.72	0.00	0.00

Table 6.13. Attribute u_{ae} related measurements for building geometry approach

Zone #	Base Area Summation (m^2)	Zone Area (m^2)	Structural Density
1	65993.85	336376.00	0.20
2	18588.56	47323.60	0.39
3	16727.23	60348.20	0.28
4	39042.15	128254.00	0.30
5	27449.92	126456.00	0.22
6	52169.82	130421.00	0.40
7	49587.56	158666.00	0.31
8	29182.51	82884.40	0.35

Table 6.14. Attribute p related measurements for building geometry approach

Zone #	Total Built Area (m^2)	Population (person)	Zone Area (m^2)	Population density (person / ha)
1	197004.00	8762	336376.00	260.48
2	71703.66	3189	47323.60	673.87
3	42441.78	1888	60348.20	312.85
4	106988.12	4753	128254.00	370.59
5	72169.70	3199	126456.00	252.97
6	134094.92	5962	130421.00	457.14
7	111204.61	4946	158666.00	311.72
8	62715.59	2796	82884.40	337.34

Table 6.15. Attribute s_d related measurements for building geometry approach

Zone #	Water Amount (m^3)
1	612.89
2	81.99
3	0.00
4	36.28
5	15.80
6	41.31
7	33.45
8	0.00

Figure 6.32 represents the resultant LoD's of the kernel function approach. Each zone's LoD decision is derived from the decision rule application with the related attribute values given in table 6.16, table 6.17, table 6.18, and table 6.19.

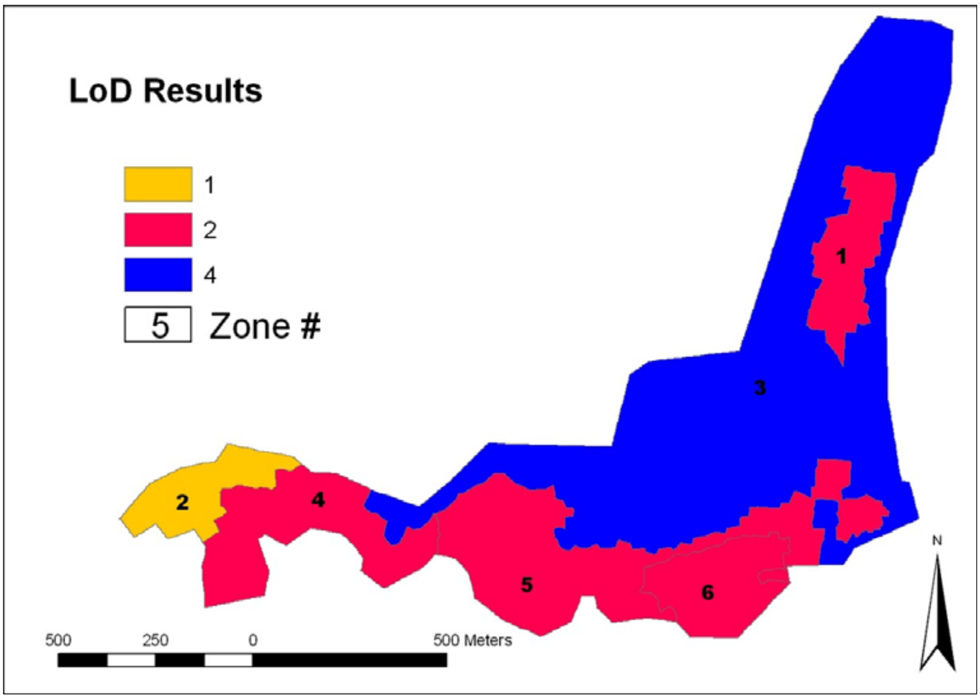


Figure 6.32. The defined LoDs of the kernel function approach

Table 6.16. Attribute d_s related measurements for kernel function approach

Zone #	Mean Elevation (m)	Coastal Length (m)	Coastal Length / Elevation
1	1.25	0.00	0.00
2	7.09	557.00	78.60
3	1.17	2108.00	1806.45
4	30.50	197.00	6.46
5	9.79	0.00	0.00
6	16.98	0.00	0.00

Table 6.17. Attribute u_{ae} related measurements for kernel function approach

Zone #	Base Area Summation (m^2)	Zone Area (m^2)	Structural Density
1	22464.10	60043.30	0.37
2	6733.99	52271.40	0.13
3	130130.15	594007.00	0.22
4	29100.70	106550.00	0.27
5	78019.82	188041.00	0.41
6	24640.06	66799.30	0.37

Table 6.18. Attribute p related measurements for kernel function approach

Zone #	Total Built Area (m^2)	Population (person)	Zone Area (m^2)	Population density (person / ha)
1	72198.29	3215	60043.30	535.45
2	13788.72	609	52271.40	116.51
3	372446.96	16556	594007.00	278.72
4	75732.07	3360	106550.00	315.35
5	181920.66	8096	188041.00	430.54
6	51519.19	2295	66799.30	343.57

Table 6.19. Attribute s_d related measurements for kernel function approach

Zone #	Water Amount (m^3)
1	0.00
2	2.62
3	799.35
4	14.39
5	0.15
6	0.00

Figure 6.33 represents the resultant LoDs of the expert opinion approach. Each zone's LoD decision is derived from the decision rule application with the related attribute values given in table 6.20, table 6.21, table 6.22, and table 6.23.

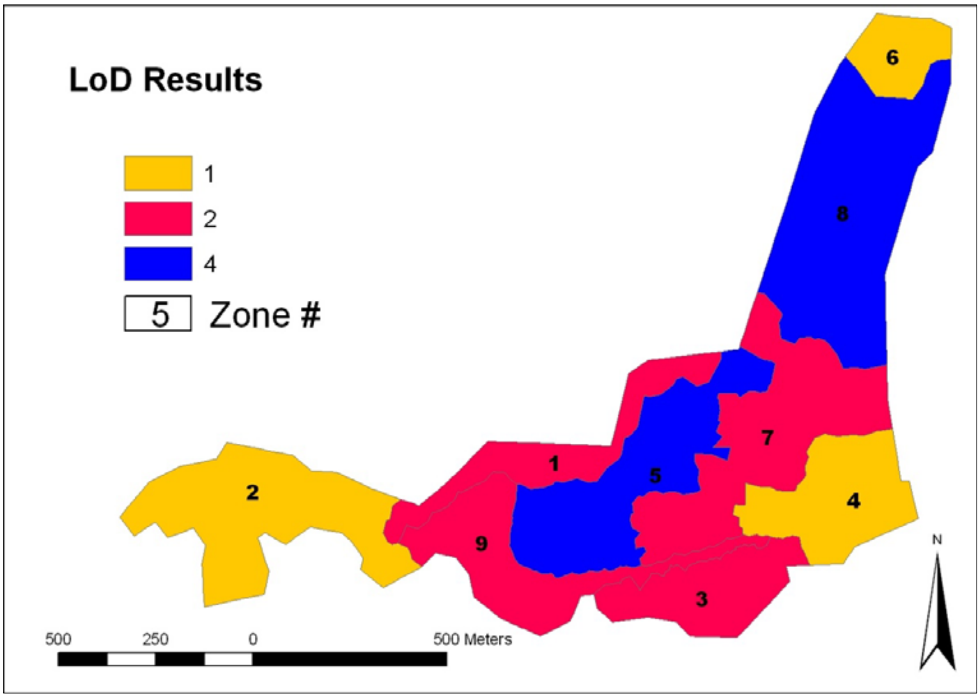


Figure 6.33. The defined LoDs of the expert opinion approach

Table 6.20. Attribute d_s related measurements for expert opinion approach

Zone #	Mean Elevation (m)	Coastal Length (m)	Coastal Length / Elevation
1	1.25	1046.25	839.62
2	21.28	834.73	39.22
3	19.00	0.00	0.00
4	2.91	0.00	0.00
5	0.87	56.50	65.14
6	0.74	131.15	177.08
7	1.54	139.90	90.66
8	1.09	652.35	600.08
9	14.26	0.00	0.00

Table 6.21. Attribute u_{ae} related measurements for expert opinion approach

Zone #	Base Area Summation (m^2)	Zone Area (m^2)	Structural Density
1	9598.70	73531.10	0.13
2	33537.74	155724.00	0.22
3	26661.78	77038.00	0.35
4	26836.84	96095.30	0.28
5	59598.91	144751.00	0.41
6	6233.59	41102.10	0.15
7	39212.19	167038.00	0.23
8	47368.12	216995.00	0.22
9	38720.50	100227.00	0.39

Table 6.22. Attribute p related measurements for expert opinion approach

Zone #	Total Built Area (m^2)	Population (person)	Zone Area (m^2)	Population density (person / ha)
1	25020.26	1112	73531.10	151.23
2	85837.30	3806	155724.00	244.41
3	55737.75	2485	77038.00	322.57
4	67829.74	3017	96095.30	313.96
5	178416.58	7937	144751.00	548.32
6	20856.57	924	41102.10	224.81
7	102750.80	4565	167038.00	273.29
8	145888.81	6494	216995.00	299.27
9	85357.14	3797	100227.00	378.84

Table 6.23. Attribute s_d related measurements for expert opinion approach

Zone #	Water Amount (m^3)
1	159.43
2	17.53
3	0.00
4	0.00
5	190.15
6	81.90
7	84.99
8	289.58
9	0.15

To come up with a comprehensive Level II LoD definition, LoD definitions of four alternative approaches were evaluated together. In this evaluation, the basic unit is voronoi area, namely buildings. The most detailed LoD definition of a voronoi area was assigned as the final LoD value of the related voronoi area (figure 6.34).

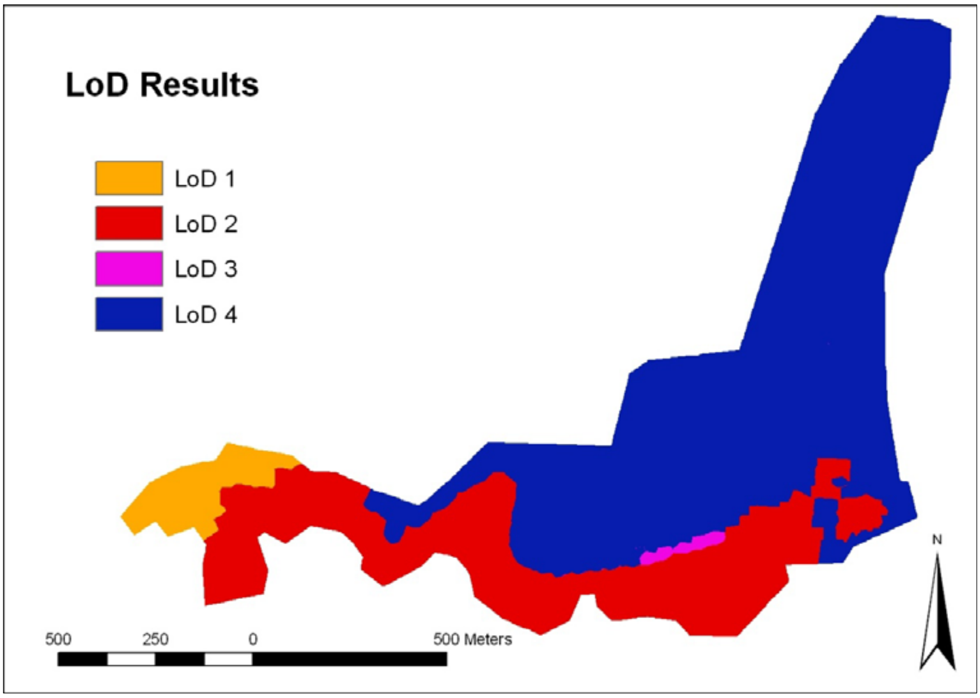


Figure 6.34. The final LoD definitions without indoor LoDs

Up to this stage of the LoD evaluation, the "i" parameter has not been taken into account. To come up with a final LoD definition for each voronoi object, sea water height output of the local numerical tsunami model was used (figure 6.35). Accordingly, if the water object reaches a voronoi object, this means that there is a need for indoor LoD and that the voronoi object gets an extra half point over the previuosly determined LoD value. Figure 6.36 represents the final LoD definitions of the Level II evaluation.

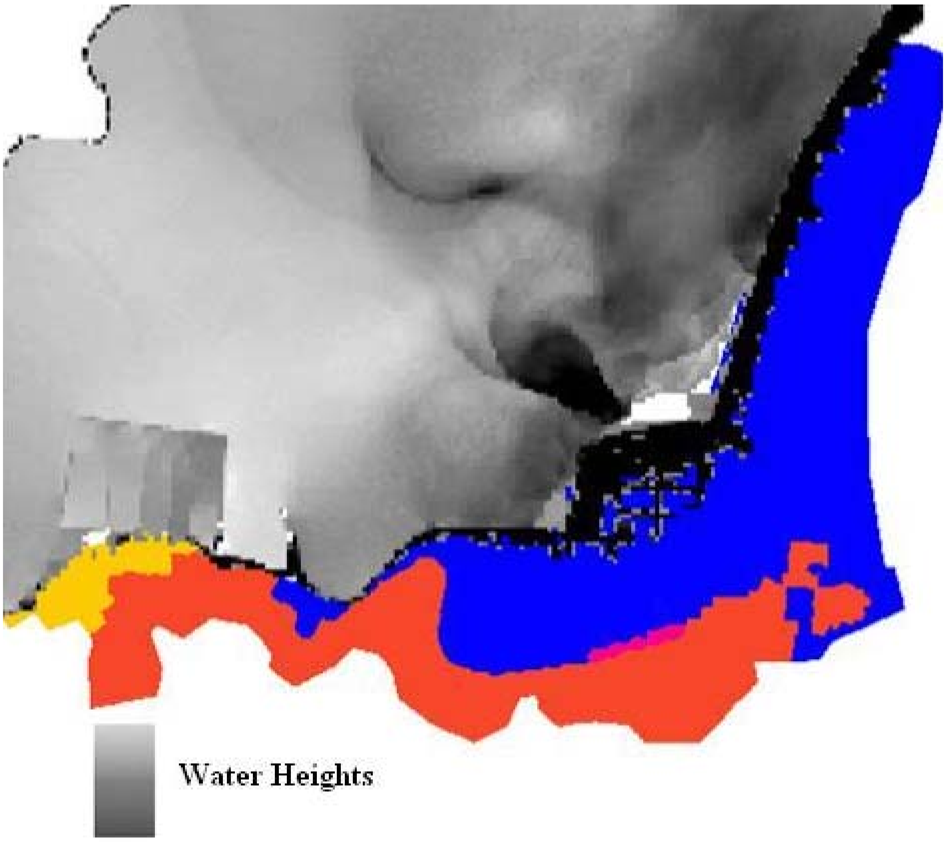


Figure 6.35. Final LoD definition with maximum wave layer needed to find indoor LoD definition of zones

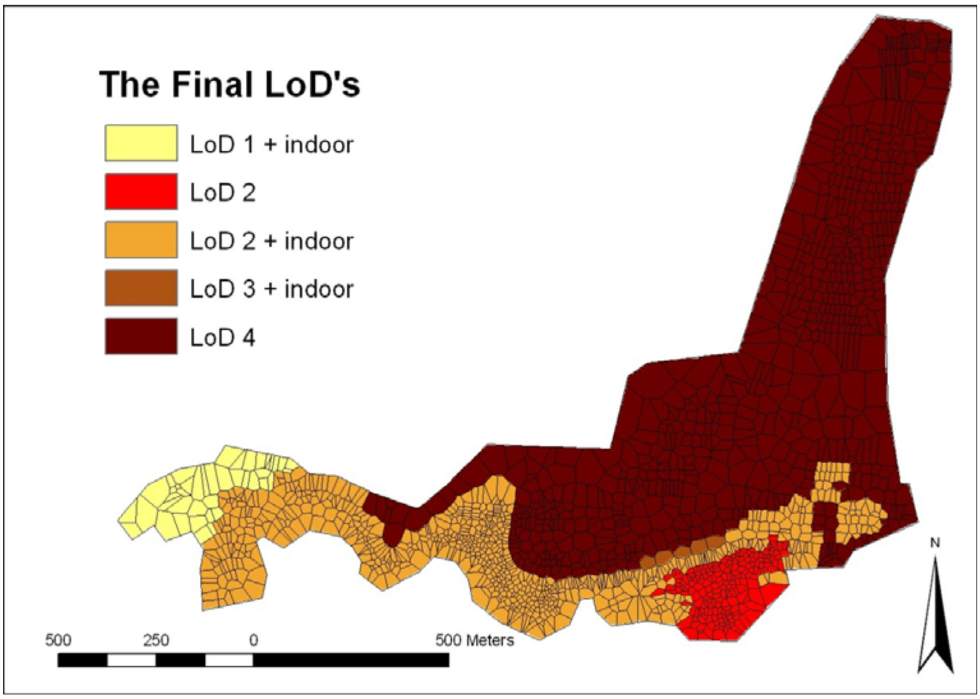


Figure 6.36. The final LoD definitions of all building objects in the implementation area

6.2.3.3 Phase III - Needs Assessment

Within the scope of the dissertation, in the tsunami implementation, the generated 3D urban environment has a building object LoD, which is the result of the Level I LoD evaluation. As it was said before, the results of the Level I decision rule indicate that appropriate LoD for building objects is LoD 1.5. In the third phase of the framework, data and process needs to create appropriate representations are studied.

Figure 6.37 represents the results of the data and process requirement analysis for this case. The letters in roman type denote object representations while the italic letters denote initial data types.

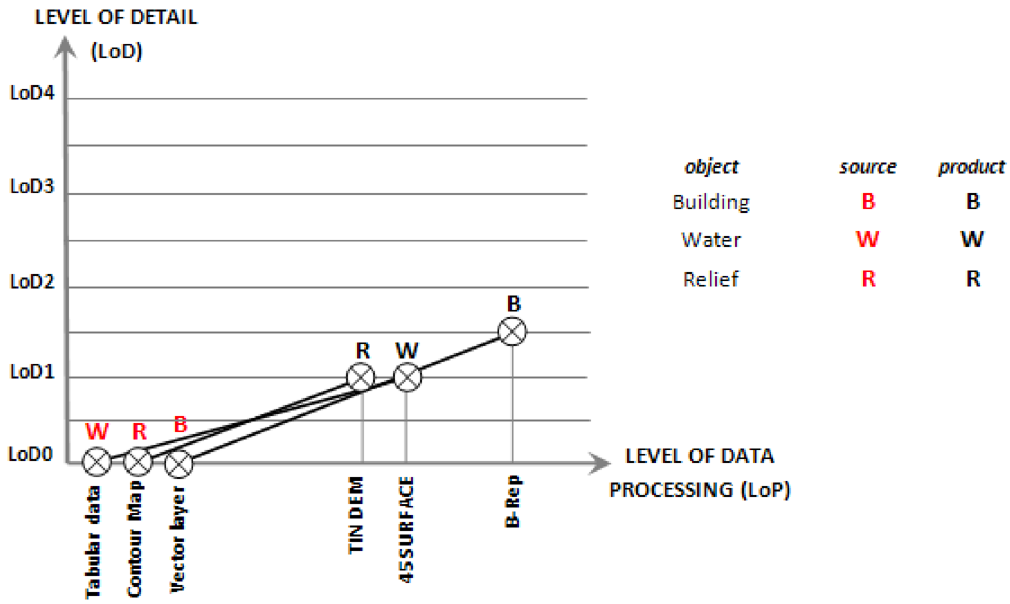


Figure 6.37. The cross-section of framework for an earthquake case

The available data for urban modeling are as follows: building footprint layer in the vector format from Municipality, and 1/25000 digital contour maps again in the vector format.

Process steps to develop an urban model involve the generation of 2.5D DEM from digital contour maps, the generation of LoD1.5 buildings by using building height information and building footprints, draping the building models with the terrain model, and water element (45 different sea surfaces which are the result of numerical tsunami model).

6.2.4 Generation of the 3D Urban Model

After the user and object definitions in the first phase, the identification of the representations with the use of the proposed decision rule in the second phase, and data and process needs analysis in the third phase, the generation of the urban virtual environment constitutes the last process of the framework.

The result of the Level I decision rule application is that LoD required for this visualization case should be 1.5. This result means that building objects should be represented with a simple box form and storey level indoor representation. The other visualization component is the hazard medium, in this case, water object. The results of numerical tsunami simulation provide input for Level I and Level II LoD evaluation; the last input of numerical tsunami simulation is the computed water height information, which constitutes the natural hazard medium of the Fethiye tsunami inundation case. The last component of the visualization environment is terrain, and the generation process and the resultant DEM (figure 6.28) are given in the Phase II - level II section of the tsunami implementation.

The generated DEM model and the ortho rectified satellite images (obtained from the Korfez Harita) were used as reference for 2D vector building footprints acquired from the Municipality. Building storey is the unit object for the desired 3D urban model. To handle storey units from building layer, building foot prints and information on number of storeys in the attribute table of the building layer were used. 6 separate storey layers were created for each storey and these layers were overlaid to the generated reference layers (DEM and ortho rectified satellite image). Water object processing steps are given in Appendix C.

In the tsunami visualization case, the process depicted in the figure 6.38, is applied. Three components are integrated in the GIS environment to take render images for each temporal state of the tsunami simulation. A video is created by using these rendered images to show the inundated areas (figure 6.39 and figure 6.40).

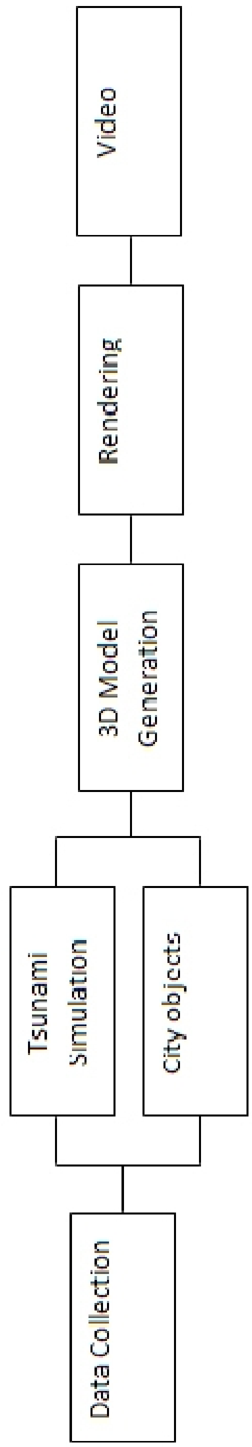
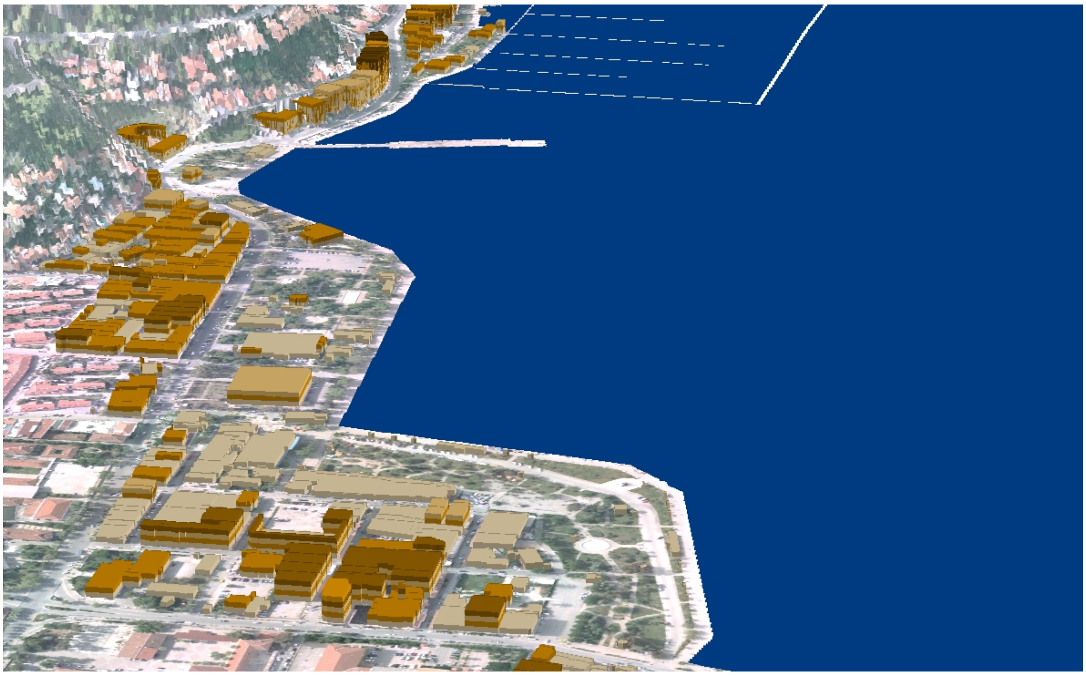
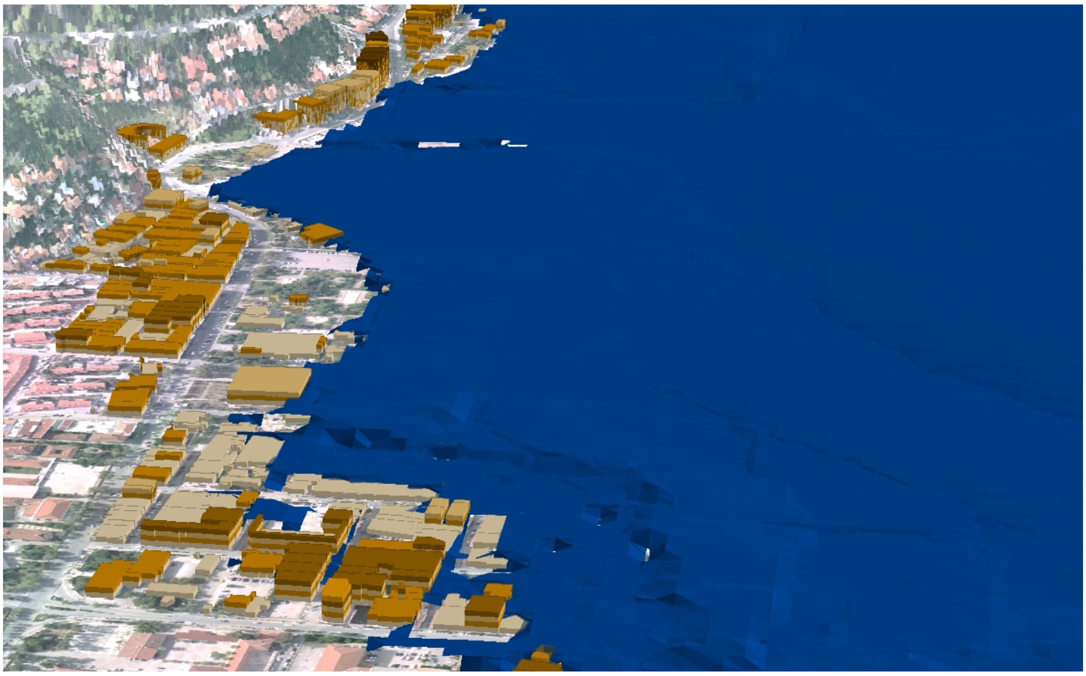


Figure 6.38. Tsunami application visualization phases

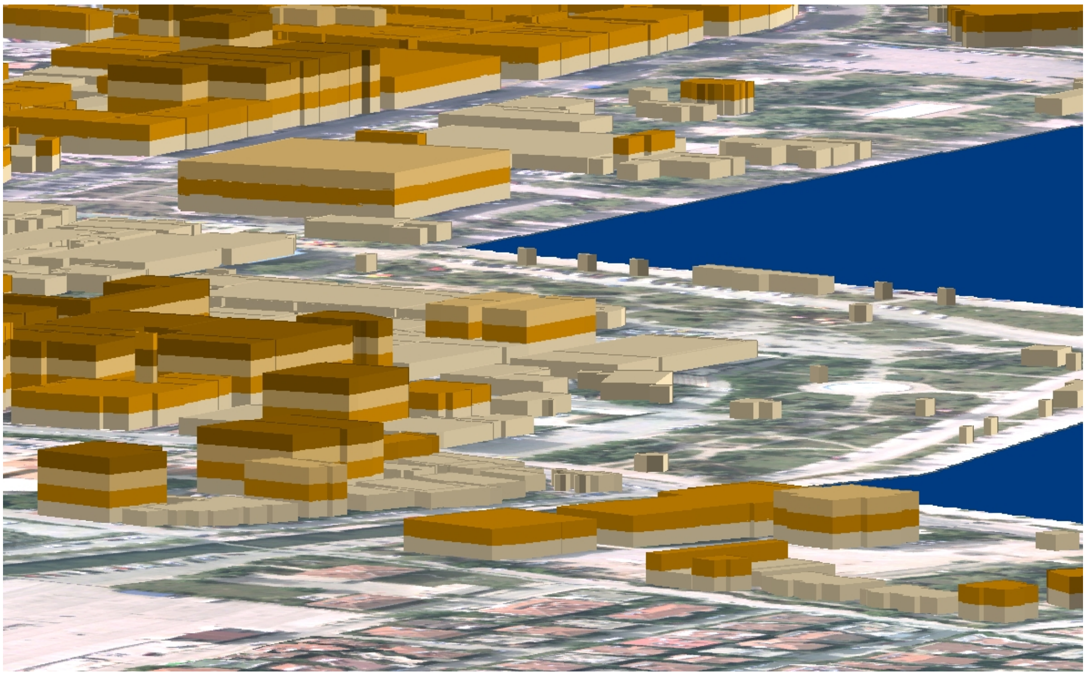


(a)

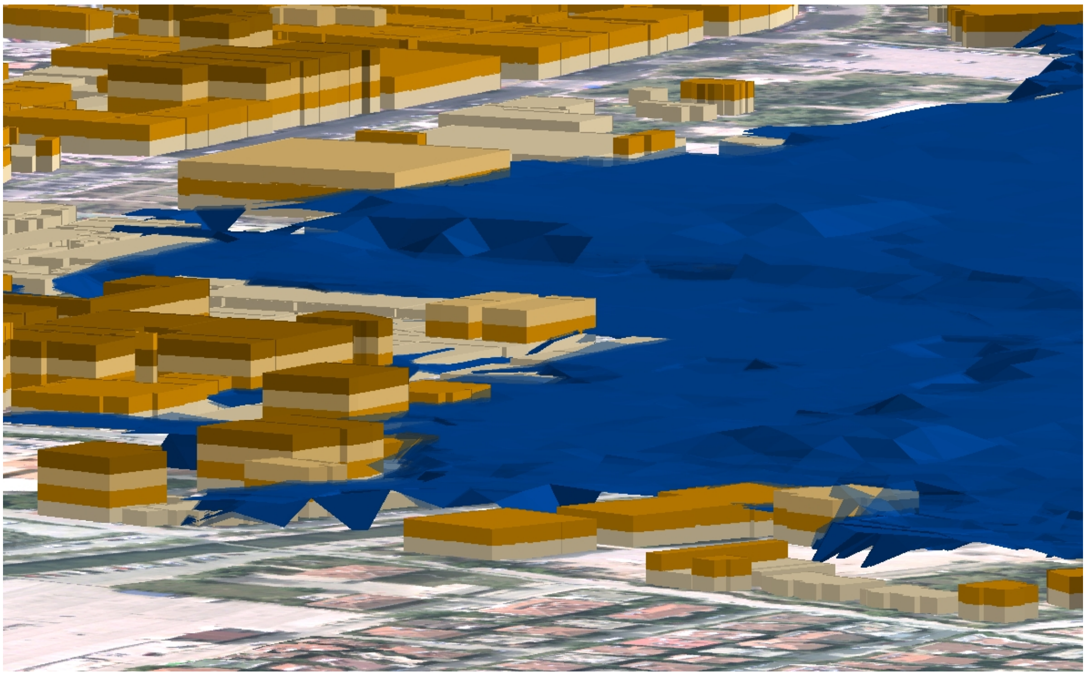


(b)

Figure 6.39. General view from the 3D city model generated for Fethiye tsunami case



(a)



(b)

Figure 6.40. Akin view from the 3D city model generated for Fethiye tsunami case

CHAPTER 7

CONCLUSIONS AND RECOMMENTATIONS

Before the general conclusions and outcomes of the proposed 3D urban disaster visualization framework, the results of two 3D urban disaster risk visualization implementations of the dissertation were discussed.

The following conclusions were reached for the Eskisehir earthquake visualization implementation and future works and plans originated from this implementation:

- The main aim of the 3D city model was the visualization of different (as total, socio-economic, structural and physical accessibility) disaster vulnerability indexes for each building in the study area.

- Effective visualization properties played important roles in all fields of the disaster risk reduction framework.

- Both model creation environments, namely CAD functions and the generated city model in GIS environment, have their pros and cons. GIS intrinsically uses tabular and geographic data. This characteristic is the main superiority of GIS environment over CAD. Another environment used for the model generation is CAD, which provides advanced visualization properties. The integration of CAD and GIS visualizations will be searched in the future studies. Other disaster vulnerability indicators such as physical or socio-economic vulnerabilities and the visualization of all these indicators in a spatial database will also be searched in the future studies.

- The CAD technology used for the model generation enables advanced visualization properties, which improve decision maker's perception level. Accurate roof modeling and terrain knowledge are the basic deficiencies of the generated model. To improve the reality level of this kind of models, the integration of photogrammetric and active sensor methods may constitute future plans.

- The coding of small GUIs can help non-expert GIS users for effective visualisation.

The following conclusions were reached for the Fethiye tsunami visualization implementation and future works and plans originated from this implementation:

- In this implementation, 3D urban visualization model for disaster management framework and its decision rule were employed for Fethiye tsunami inundation visualization case.

- This particular case confirmed the validity of the decision rule for tsunami case. The technical disaster decision-maker group can use it as a tool to decide on the needed levels of details in the 3D model representations.

- In addition, it provides indications about the indoor features for a particular disaster simulation and/or visualization application.

- The study has also shown that a GIS-based analysis could constitute one of the future works, the definition of accessibility of the essential community facilities which are significantly impaired due to transportation infrastructure damage during a tsunami.

- In the decision rule, a multi-zonal evaluation approach of different city districts could constitute another future work. With such an approach, a more detailed analysis of city could be possible.

In the light of the results of these two implementations, it could be said that natural hazards affecting large areas can have more sparse effects on urban areas. As a result, large urban areas should be studied in a more generalized manner. On the other hand, the effects of natural hazards affecting small areas should be studied in more detail. The susceptibility level of the city in which the natural disaster occurs is another multiplier factor. A hazardous event occurring in a more resilient city cannot cause as much destruction as in a susceptible city. This result in that assessment which the framework needs could not be completed independently of the city. As a result, each natural hazard – urban deuce is an application area of the proposed framework.

The following intellectual and scientific merits are achieved by the proposed research:

- The conceptual framework forms the basis of 3D visualizations of natural disaster risk in urban areas. In this way, a general guideline for 3D visualizations of urban environment with contextual information (natural disaster risk) is provided.

- Risk communication tool: The 3D visualization of urban environment with natural disaster risk is achieved seeing the effectiveness of several risk reduction scenarios.

- The guideline of user needs in 3D visualization: This guideline allows customization of 3D disaster risk visualization for the needs of disaster management stakeholders.

The proposed conceptual 3D urban visualization framework will lead up to more effective results and increased benefits for stakeholders of disaster management by means of a risk communication tool. The main contributions of this framework are:

- It provides improved risk communication levels among the stakeholders of disaster management and efficient disaster management decision processes

- It is a pioneer guide for the future 3D urban disaster management studies

- The systematic nature of the framework reveals the future needs for 3D urban disaster management visualization

- The flexible characteristics of the framework allows the integration of new technologies in 3D urban visualization

The proposed framework draws a link between the disaster type and the needed 3D model for an appropriate 3D visualisation. Eight attributes are incorporated into the proposed decision rule to establish a link between the hazard type and the LoD needed in a 3D urban model for visualization. The attributes are divided into two main groups: hazard-related attributes, including f (frequency), d (duration), s_o (speed of onset), s_d (spatial dispersion), and i (indoor penetration); and urban-related attributes, including d_s (disaster susceptibility), u_{ae} (urban areal extent) and p (population density). The variable D (level of indoor/outdoor detail) directly provides the needed LoD of the 3D model.

Although the first applications of this approach are very promising, further tests with different cities, countries and disasters are needed. Three of the attributes (s_o, d, i) are related to the empirical characteristics of the considered hazard. Five (f, s_d, a_e, u_{ae}, and p) are related to the local specification of the hazard and the settlement considered for the 3D urban modeling application. Attributes with local specifications are case-dependent. For example, the same hazard case may need a different model detail level in a different settlement. The reverse is also true. The same settlement may require different 3D models if different types of hazards are considered. Future research can investigate these possibilities in detail.

Risk managers (and other stakeholders) can use the framework as a tool to determine the necessary data types for 3D models, used in a particular simulation and/or visualization application. The main expected benefit of this proposed framework is the ability to create understandable, yet well-balanced 3D models to be used as risk communication tools.

This dissertation shows that developments in CityGML, 3D data sources, data processing and 3D visualization can easily be adapted to the framework. The feedbacks from the interviewed risk managers show that the initial applications of the framework are quite promising.

The *level of data processing* introduced to the literature by this dissertation is a new concept. The study represents one application area of this new concept, in addition to this specific area; it may find wider applications. According to the first review results, the new term has a potential to become a basic term for geospatial environment to compare data, model and products. Even all kinds of positive sciences, which contain data collection, preparation and modeling stages, may have benefits from this new term. However, the concept of the level of data processing demands further elaboration to gain a basic generic term. Currently, the level of data processing is established by a rough estimation of the resources and processes needed to obtain a specific model. Further investigations are needed to define the appropriate parameters that influence the data processing efforts. These parameters will most likely be specific to the data-processing unit of various disaster management organizations.

More research and development is needed to formally define the relations and dependencies between users and elements at risk. A set of criteria should be developed, according to which 3D objects can be selected from the object pool.

The framework is constructed on the idea of effective use of limited resources. There is no need to such an approach only in case of unlimited financial and human resources. Based on this point, all disaster management stakeholders and persons or corporations who have responsibilities relevant to the urban can benefit from the usage of the proposed framework. This benefit will vary depending on the application scale or the responsibility of the practitioner.

The proposed framework with proposed components like three-level urban object evaluation, building object LoD hierarchy with indoor, and zonation approach to find the homogeneous sub-urban zones will benefit urban planning discipline as well as in disaster management. Urban planning is a discipline dealing with spatial problems ranging from the country scale to the single building scale, so these definitions and methods can be tools for planners to access consistent decisions at various stages of planning. These stages could be summarized as problem definition, goal formulation, evaluation of alternatives, choice, implementation and monitoring. In a general view, the proposed framework as a whole works for the stages of problem definition and goal formulation, which constitute the policy and the general strategy of the plan. The proposed zonation approach can find application areas for the evaluation of alternatives to find the proper choice. The last 3D urban object representation hierarchy with indoor can provide the path to reach more realistic results for related resolution.

REFERENCES

Albert, J., M. Bachmann, A. Hellmeier, 2003, Zielgruppen und Anwendungen für Digitale Stadtmodelle und Digitale Geländemodelle, Erhebungen im Rahmen der SIG 3D der GDI NRW

Alexander, D.E., 1986, Landslide Damage to Buildings, Environmental Geology and Water Science 8, 147-51

Altinok, Y., B. Alpar, N. Ozer, and H. Aykurt, 2011, Revision of the Tsunami Catalogue Affecting Turkish Coasts and Surrounding Regions, Natural Hazards and Earth System Sciences 11: 237-291

Azimi, A. & Delavar, M.R., (2007), Quality Assessment in Spatial Clustering of Data Mining, Presented at the 5th International Symposium of Spatial Data Quality, Netherlands

Azuma R., 1997, A Survey of Augmented Reality, Presence: Teleoperators and Virtual Environments vol. 6, no. 4, Aug. 1997, pp. 355-385.

Baillard C., and H. Maître, 1999, 3D Reconstruction of Urban Scenes from Aerial Stereo Imagery: A Focusing Strategy, Computer Vision and Image Understanding, vol. 76, no. 3, pp. 244-258

Balk, D., G. Yetman, 2004, The Global Distribution of Population: Evaluating the gains in resolution refinement, Center for International Earth Science Information Network (CIESIN), Columbia University, Basta, C., J.M.M. Neuvel, S. Zlatanova and B. Ale, 2007, Risk-maps informing land-use planning processes: A survey on the Netherlands and the United Kingdom recent developments, Journal of Hazardous Materials, Vol. 145, pp. 241-249

Bellman, J., and M.R. Shortis, 2002, A Machine Learning Approach to Building Recognition in Aerial Photographs, Proc. Photogrammetric Computer Vision (PCV 02), part A, Int'l Soc. Photogrammetry and Remote Sensing (ISPRS), pp. 50-55

Benner, J., A. Geiger and K. Leinemann, 2005, Flexible generation of Semantic 3D building models, In: Proc of the 1st Intern. Workshop on Next Generation 3D City Models, Gröger/Kolbe (Eds.), Bonn, pages 17-22

Bevan, N. and I.Curson, 1999, Planning and Implementing User Centred Design Using ISO 13407, In: CHI'99 Adjunct Proceedings, CHI'99 Adjunct Proceedings, Pittsburgh 15-20 May 1999 ACM

Billen, R., 2000, Integration of 3D information in Uban GIS: a conceptual view, ISPRS 2000, Amsterdam, Pays-Bas

Billen, R., F. Laplanche, S. Zlatanova and L. Emgård, 2008, Vers la création d'un méta-modèle générique de l'information spatiale 3D urbaine (in French), In: Revue XYZ, No. 114, 1er trimestre 2008, pp. 37-42

Bitzer, K., and R. Pflug, 1989, DEPOD: A Three Dimensional Model for Simulating Clastic Sedimentation and Isostatic Compensation in Sedimentary Basins, Quantitative Dynamic Stratigraphy, ed. T. A. Cross, Prentice Hall, Englewood Cliffs, New Jersey, 335-348

Blake, M., S. Openshaw, 1995, Using Neurocomputing Methods to Classify Britain's Residential Areas, in P. Fisher (Ed) Innovation in GIS 2 Taylor and Francis, London

Bureau of the Census, U.S., 1994, Department of Commerce, Geographic Areas Reference Manual, Washington, DC: Bureau of the Census, http://www.census.gov/geo/www/garm.html Accessed May 5, 2011

Burton, I., Robert, W.K. and Gilbert, F.W., 1993, the Environment as Hazard, Guilford Press, New York

Castagneri, J., 1998, Temporal GIS explores new dimensions in time, GIS world, vol. 11, no. 9, pp. 48-51

Chang R., G. Wessel, R. Kosara, E. Sauda and W. Ribarsky, 2007, Legible Cities: Focus-Dependent Multi-Resolution Visualization of Urban Relationships, IEEE Transactions on Visualization and Computer Graphics, Vol. 13, No. 6, november/December

Christie, R.D., 1994, Towards a Higher Level of User Interaction in the Energy Management Task, IEEE International Conference on Systems, Man, and Cybernetics, 1994. 'Humans, Information and Technology, pages, 1086 - 1091 vol.2

Comanicu D., P. Meer, 2002, Mean shift: A Robust Approach Toward Feature Space Analysis, IEEE Trans. Pattern Anal. Machine Intell., 24, 603-619, May 2002

Coors, V., S. Flick, 1998, Integrating Levels of Detail in a Web-based 3D-GIS, Proc. 6th ACM Symp. on Geographic Information Systems (ACM GIS 98), Washington D.C., USA

Cox, S., P. Daisy, R. Lake, C. Portele, and A. Whiteside, 2004, OpenGIS Geography Markup Language (GML 3.1), Implementation Specification Version 3.1.0, Recommendation Paper OGC Doc. No. 03-105r1

DAD, 2009, General Directorate of Disaster Affairs Earthquake Research Department (DAD) earthquake database, DAD Earthquake catalogue data http://sismo.deprem.gov.tr/

Derpanis, K.G., 2005, Mean Shift Clustering, In Computer Vision Related Notes, Summary of Mean Shift clustering. Retrieved from: http://www.cse.yorku.ca/~kosta/CompVis_Notes/mean_shift.pdf (Last accessed on 10.01.2011)

Döllner J., B. Hagedorn, 2007, Integrating urban GIS, CAD, and BIM data by service-based virtual 3D city models, In Coors, Rumor, Fendel & Zlatanova (eds.), Urban and regional data management: UDMS annual 2007 (pp. 157-170), Taylor & Francis Group, London, UK

Duzgun, H.S.B., S. Lacasse, 2005, Vulnerability and Acceptable Risk in Integrated Risk Assessment Framework, Landslide risk management: proceedings of the International Conference on Landslide Risk Management, Vancouver, Canada, 31 May-3 June 2005

Duzgun, H.S.B., Yucemen, M.S., Kalaycioglu, H.S., Celik K., Kemec, S., Ertugay K., Yilmaz N., 2011, An Integrated Earthqake Vulnerability Assessment Framework for Urban Areas, Natural Hazards, Published online: 27 April 2011, DOI: 10.1007/s11069-011-9808-6

El-Sheimy, N., C. Valeo, and A. Habib, 2005, Digital Terrain Modeling: Acquisition, Manipulation, and Applications. Artech House, Published July 2005, ISBN 1580539211

Emgard, L., and S. Zlatanova, 2008, Implementation alternatives for an integrated 3D information model, in: Van Oosterom, Zlatanova, Penninga and Fendel (eds.), 2008, Advances in 3D Geoinformation Systems, Lecture Notes in Geoinformation and Cartography, Springer-Verlag, Heidelberg, pp. 313-329

Ergin, O., 2007, M.Sc. Thesis, “Modeling Building Height Errors in 3D Urban Environments”, Geodetic and Geographic Information Technologies, Middle East Technical University, Ankara, Turkey

Evren Y., 2007, Istanbul Merkez Bolge’de Butunlesme ve Ayrisma: 15. ISOCARP Genc Profesyonel Plancılar Calistayi’nin Dusundurdukleri, Yildiz Technical University Faculty of Architecture Faculty, E-Journal, Volume 2, Issue 1, p.11-21

Fedetov, S.A., 1985, Estimates of Heat and Pyroclas Discharge by Volcanic Eruptions Based upon the Eruption Cloud and Steady Plume Observations, Journal of Geodynamics 3, 275-302

Fincke, T., V. Lobo, F. Bacao, 2008, Visualizing Self-Organizing Maps with GIS, Presented at the International Conference of Geoinformatika 2008, Munich, Germany

Foley, J., A. van Dam, S. Feiner, J. Hughes, 1995, Computer Graphics: Principles and Practice, Addison Wesley, 2nd Ed.

Frueh, C., and A. Zakhor, 2001, 3D Model Generation for Cities Using Aerial Photographs and Ground Level Laser Scans, Proc. Conf. Computer Vision and Pattern Recognition, IEEE CS Press, vol. 2.2, pp. 31-38

Galster, G., Freiberg, F. and Houk, D.L., 1987, Radical Differentials in Real Estate Advertising Practices: An Exploratory Case Study, Journal of Urban Affairs, 9, p. 199-215

Ganter, J.H., 1988, Interactive Graphics: Linking the Human to the Model, Proceedings of GIS/LIS 1988, San Antonio, Texas, pages:230-239

George, V., and D. Sander, 2001, 3D Building Model Reconstruction from Point Clouds and Ground Plans, Proc. ISPRS Workshop Land Surface Mapping and Characterization Using Laser Altimetry, ISPRS, pp. 37-43

Gröger, G., Kolbe, T.H., Czerwinski, A., 2006, CityGML Implementation Specification, Developed by the Special Interest Group 3D (SIG 3D), OGC Document Number 06-057r1

Goodchild, M.F., 2008, Geographic information science: the grand challenges, In J.P. Wilson and A.S. Fotheringham, editors, The Handbook of Geographic Information Science. Malden, MA: Blackwell, pp. 596–608

Gould J.D., and C. Lewis, 1987, DEsiging for Usability: Key Principles and What Designers Think, In: Baecker , R.M. and Buxton, W.A.S. (eds.), Readings in Human-Computer Interaction: A Multidisciplinary Approach, San Mateo, CA: Morgan Kaufmann Publishers, Inc., pp. 528-539

Gouin, D., P. Evdokiou and R. Vernik, 2004, A Showcase of Visualization Approaches for Military Decision Makers, Defence Research And Development Canadavalcartier (Quebec)

Gouin D., Evdokiou P., Vernik R., 2002, A Showcase of Visualization Approaches for Military Decision Makers, RTO IST Workshop on "Massive Military Data Fusion and Visualization: Users Talk with Developers", Halden, Norway, 10-13 September 2002, published in RTO-MP-105

Haddow, G.D. and J.A. Bullock, 2003, Introduction to Emergency Management, Butterworth-Heinemann, Stoneham, MA

Harrower, M., 1999, A Conceptual Framework for Mapping Space-Time, in: Proceedings at the 95th Annual Meeting of AAG, Honolulu, Hawai, 14 pages

Herring, J., 2001, The OpenGIS Abstract Specification, Topic 1: Feature Geometry (ISO 19107 Spatial Schema), Version 5, OGC Document Number 01-101

Herold, S., Sawada, M. and Wellar, B., 2005, Integrating Geographic Information Systems, Spatial Databases and the Internet: A Framework for Disaster Management, Proceedings of the 98th Annual Canadian Institute of Geomatics Conference, Ottawa, Canada, June 13, 2005

Hijazi, I, M. Ehler and S. Zlatanova, 2010, BIM for geo-analysis (BIM4GEOA): set up of 3D information system with open source software and open specifications (OS), In: Kolbe, Köning, Nagel (Eds.); International Archives of the Photogrametry, Remote sensing and Spatial Information Sciences, Volume XXXVIII-4/W15, November 4-5, 2010, Berlin, Germany, pp. 45-49

Hopgood, F.R.A., D.A. Duce, E.V.C. Fielding, K. Robinson, A.S. Williams, 1986, Methodology of Window Management, Proceedings of an Alvey Workshop at Cosener's House, Abingdon, UK, Springer-Verlag,

Hu, J., You S. and Neumann U., 2003, Approaches to Large-Scale Urban Modeling, IEEE Computer Graphics and Applications, Published by the IEEE computer Society, November/December (2003, page:62-69

IAI, 2007, International Alliance for Interoperability, IFC model specification, www.iai-international.org

IDB (Inter-American Development Bank), 2000, Facing the Challenge of Natural Disasters in Latin America and the Caribbean, An IDB Action Plan. IDB publication, Sustainable Development Department, Special Report, 27 pp

Isikdag, U. and S. Zlatanova, 2009, Towards defining a framework for automatic generation of buildings in CityGML using BIM, in Lee and Zlatanova (Eds.), 3D geo-information sciences, LNG&C, Springer Verlag, pp. 79-96

Jones, C.B., 1989, Data structures for three-dimensional spatial information systems in geology. Int. Journal of Geographic Information System (IJGIS), Vol. 3, No. 1, pp. 15-31

Joseph, M., 2007, A Gis-Based Modeling Of Environmental Health Risks In Populated Areas Of Port-Au-Prince, Haiti, Master Thesis, The University Of Arizona, http://www.memoireonline.us/01/09/1868/A-GIS-based-modeling-of-environmental-health-risks-populated-areas.html

Karas, I.R., F. Batuk, A.E. Akay, I. Baz, 2006, Automatically Extracting 3D Models and Network Analysis for Indoors, Innovations in 3D Geoinformation Science, Series: Lecture Notes in Geoinformation and Cartography, Eds: A. Abdul-Rahman, S. Zlatanova, V. Coors, Springer Verlag, Berlin Heidelberg, Pages: 395 - 404,

Kaplan, L.G., 1996, Emergency and Disaster Planning Manual, McGraw-Hill, New York, NY

Kemec, S. and Duzgun, S., 2006a, 3D Visualization for Urban Earthquake Risk in Geohazards, Farrokh Nadim, Rudolf Pöttler, Herbert Einstein, Herbert Klapperich, and Steven Kramer Eds, ECI Symposium Series, Volume P7

Kemec S. and H.S. Duzgun, 2006b, “Use of 3D Visualization in Disaster Risk Assessment for Urban Areas” in Lecture Notes in Geoinformation and Cartography Series, Innovations in 3D Geo Information Systems, Alias Abdul-Rahman, Sisi Zlatanova and Volker Coors (Eds.), New York: Springer, Pages: 557-566, DOI: 10.1007/978-3-540-36998-1_43

Kemec, S, S. Zlatanova and S. Duzgun, 2009, Selecting 3D urban Visualisation models for disaster management: a rule-based approach, in Proceedings of TIEMS 2009 Annual Conference, June 9-11, Istanbul, Turkey, pp. 99-110

Kemec, S., H.S. Duzgun, and S. Zlatanova, 2010, A framework for defining a 3D model in support of risk management, in Geographic Information and Cartography for Risk and Crisis Management, Konecny, M., S. Zlatanova, B. L. Temenoujka (Eds.), New York: Springer, Pages: 69-83, DOI: 10.1007/978-3-642-03442-8_5

Kerle, N., S. Heuel, and N. Pfeifer, 2008, Real-Time Data Collection and Information Generation Using Airborne Sensors, In Geospatial Information Technology for Emergency Response, Zlatanova, S., Li, J. (eds.), Taylor and Francis, p.43-74

Kolbe, T.H., G. Gröger, 2004, Unified Representation of 3D City Models, Geo-information Science Journal, Vol.4, No. 1

Kolbe, T.H., Gröger G., Plümer L., 2005, CityGML-Interoperable Access to 3D City Models, Oosterom, Zlatanova, Fendel (Eds.): Proceedings of the Int. Symposium on Geo-information for Disaster Management on 21-23 March 2005 in Delft, Springer Verlag

Kohonen, T., 1995, Self-Organizing Maps, Berlin: Springer-Verlag

Koua, E.L., and M. J. Kraak, 2005, Evaluating Self-Organizing Maps for Geovisualization, In Exploring Geovisualization J. Dykes, A.M. MacEachren, M.-J Kraak (Editors), published by Elsevier Ltd., pages: 627-643

Köninger, A. and S. Bartel, 1998, 3D-GIS for Urban Purposes, Geoinformatica, 2(1):79-103(1998)

Lattuada, R., 2006, Three-dimensional representations and data structures in GIS and AEC, In: Zlatanova, S. and Prosperi, D. (eds.): Large-scale 3D data integration - Challenges and Opportunities. Taylor&Francis, London, pp. 57-86

Lin C., and R. Nevatia, 1998, Building Detection and Description from a Single Intensity Image, Proc. Computer Vision and Image Understanding (CVIU), vol. 72, no.2, Elsevier Science, pp. 101-121

Lin H. and Q. Zhu, 2005, Virtual Geographic Environments, In: S. Zlatanova and D. Prosperi, Editors, Large scale 3D data integration—challenges and opportunities, Taylor & Francis (CRCpress), Boca Raton

MacEachren A.M., and M.J. Kraak, 2001, research challenges geovisualization Cartography and Geographic Information Science Volume: 28 Issue: 1 ISSN: 1523-0406

Mach, R., P. Petschek, 2007, Visualization of Digital Terrain and Landscape Data A Manual, Springer Berlin Heidelberg New York

Malczewski, J., 1999, GIS and Multicriteria Decision Analysis, New York: Wiley

Malczewski, J., 2006, GIS-Based Multicriteria Decision Analysis: A Survey of the Literature, International Journal of Geographical Information Science, 20:7,703 - 726

Manual of Photogrammetry Fourth Edition, 1980, American Society for Photogrammetry and Remote Sensing

Manual of Photogrammetry Fifth Edition, 2004, American Society for Photogrammetry and Remote Sensing

Marincioni, F., 2007, Information Technologies And The Sharing Of Disaster Knowledge: The Critical Role Of Professional Culture, Disasters, 31(4): 459−476. Blackwell Publishing, USA

Mark, D. (Editor), 1999, NSF Workshop Report, Geographic Information Science: Critical Issues in an Emerging Cross-disciplinary Research Domain, NSF, Washington, DC

Martin, D., and Higgs, G., 1997, The Visualization of Socio-Economic GIS Data Using Virtual Reality Tools, Transactions in GIS, vol.1, no.4, p.255

Medyckyj-Scott, D. and H. Hearnshaw, 1993, Human Factors in Geographic Information Systems, Belhaven Press, London, 266 pp.

Miller, C.L. and R.A. Laflamme, 1958, The Digital Terrain Model-Theory & Application, MIT Photogrammetry Laboratory

Mitroff, I.I., 1988, Crisis management: cutting through the confusion, Sloan Management Review, Vol. 29 No. 2, pp. 15-20

Molenaar, M., 1992, A topology for 3D vector maps, ITC Journal 1992-1

Nevatia R., and A. Huertas, 1998, Knowledge-Based Building Detection and Description, Proc. DARPA 98: Image Understanding Workshop, DARPA, pp. 469-478

Newhall, C.G., and S. Self, 1982, the Volcanic Explosivity Index (VEI): An Estimate of Explosive Magnitude for Historical Volcanism, Journal of Geophysical Research 87, 1231-8

Norbert H., and K. Anders, 1997, Acquisition of 3D Urban Models by Analysis of Aerial Images, Digital Surface Models and Existing 2D Building Information, Proc. SPIE Conf. Integrating Photogrammetric Techniques with Scene Analysis and Machine Vision III, SPIE, pp. 212-222

Ok, A.O., 2005, Accuracy Assessment of the DEM and Orthoimage Generated from ASTER, Thesis Submitted to the Geodetic and Geographic Information Technologies, Middle East Technical University, Ankara, Turkey

Oosterom, P., J. Stoter, W. Quak, S. Zlatanova, 2002, The balance between geometry and topology, In Richardson, D, Oosterom, P (eds.): Advances in Spatial Data Handling. Proc. of 10th Int. Symp. SDH 2002, Springer, Berlin

Ott, T. and F. Swiaczny, 2001, Time Integrative Geographic Information Systems, Springer, Heidelberg

Ozer C., D.I. Dilmen, S. Kemec, A.C. Yalciner, A. Zaytsev, A. Chernov, I. Insel, E. Pelinovsky, H.S. Duzgun, 2009, "GIS Based Inundation Mapping, Examples from Mediterranean and South China Sea", South China Sea Tsunami Workshop 3 SCSTW3, in Penang, Malaysia

Özmen, B., M. Nurlu, H. Güler, 1997, Coğrafi Bilgi Sistemi ile Deprem Bölgelerinin İncelenmesi, Bayındırlık ve İskan Bakanlığı, Afet İşleri Genel Müdürlüğü, Ankara

Ozmutlu, S., 1999, Book - CDROM review: 1) 3D Geoscience Modeling: Computer techniques for geological Characterization, Simon W. Houlding (1994). 2) Practical Geostatistics, Modeling and Spatial Analysis, Simon W. Houlding (1999), Ingeokring Newsletter no.8, pp 13-15, Haarlem, the Netherlands

Pahl, R.E., 1975, Whose City? Penguin, Harmondsworth

Peuquet, D.J., 2002, Representations of Space and Time, The Guilford Press, New York/London

Pflug R., J. W. Harbaugh, 1992, Computer Graphics in Geology: Three-Dimensional Computer Graphics in Modeling Geologic Structures and

Simulating Geologic Processes, Lecture Notes in Earth Sciences, Published by Springer-Verlag. 298 pages, ISBN 3540-55190-5,

Pfund, M., 2002, 3D GIS Architecture, GIM International 2/2002

Poullis, C., and S. You, 2009, Photorealistic Large-Scale Urban City Model Reconstruction, IEEE Transactions on Visualization and Computer Graphics, Vol. 15, No. 4, July/August

Raper, J.F., 1989, The 3D Geoscientific Mapping and Modeling System: A Conceptual Design, In Raper, J.F. (eds.) Three dimensional Applications in Geographical Information Systems, London, Taylor and Francis, p.11-20

Ribarsky, W., T. Wasilewski, and N. Faust, 2002, From Urban Terrain Models to Visible Cities, IEEE Computer Graphics and Applications, vol. 22, no. 4, pp. 10-15

Richardson, B., 1994, Socio-Technical Disaster: Profile and Prevalence, Disaster Prevention and Management, Vol. 3 No. 4, pp. 41-69

Requicha, A.A.G, H.B. Voelcker, 1982, Solid modeling: A Historical Summary and Contemporary Assessment, IEEE Computer Graphics and Applications

Requicha, A.A.G, J.R. Rossignac, 1992, Solid Modeling and Beyond, IEEE Computer Graphics and Applications

Rossi, P.H., 1955, Why Families Move: A Study in the Social Psychology of Urban Residential Mobility, Free Pres; Glencoe

Rubin, J., 1994, Handbook of Usability Testing, Wiley Technical Communication Library

Sapaz, B., V. Isler, 2006, Visualization in Transportation: A Theoretical Reference Model Framework, TRODSA: 3rd. Intl. Traffic and Road Safety Congress

Schmidt, S., Gotze, H.-J., 1998, Interactive visualization and modification of 3D-models using GIS-functions. Phys. Chem. Earth 23 (3), 289–295

Shaluf, I.M., 2007, Disaster Types, Disaster Prevention and Management, Vol. 16 No. 5, 2007, pp. 704-717

Skupin, A., R. Hagelman, 2005, Visualizing Demographic Trajectories with Self-Organizing Maps, Geoinformatica, Vol. 9, pp: 159-179.

Soloviev, V., 1978, Tsunamis, In the Assessment and Mitigation of Earthquake Risk, Paris: UNESCO Press

Speare, A., Goldstein, S. and Frey, W.H., 1975, Residential Mobility, Migration and Metropolitan Change, Balinger, Cambridge.

Sudhira, H.S., T.V. Ramachandra, K.S. Jagadish, 2004, Urban sprawl: metrics, dynamics and modeling using GIS, International Journal of Applied Earth Observation and Geoinformation 5 (2004) 29–39

Tao, C.V., 2006, 3D Data Acquisiton and Object Reconstruction for AEC/CAD, in Large-Scale 3D Data Integration Challenges and Opportunities, edited by Zlatanova, S., Prosperi, D., Taylor and Francis, p39-56

Tegtmeier, W., P.J.M. van Oosterom, S. Zlatanova, and H.R.G.K. Hack, 2008, Geology as part of an integrated 3D information model including sub - surface real world and design information. Presented at Open Geospatial Consortium Inc. (OGC) Technical Committee Meeting, 1-5 December 2008, Valencia, Spain.

Thomas D.S.K., Ertugay, K. and Kemec, S., 2006, The Role of Geographic Information Systems/Remote Sensing in Disaster Management, in Handbook of Disaster Research, Rodriguez, H., Quarantelli, E.L., and Dynes, R. (Eds.) New York: Springer, Pages: 83-96

Tinti S., I. Gavagni, A. Piatanesi, 1994, A finite-element numerical approach for modelling tsunamis, Annali di Geofisica,Vol XXXVII, N.5, 1994

Tsuya, H., 1955, Geological and Petrological Studies of Volcano Fuji, Tokyo Daigaka Jishin Kenkyusho Iho 33, 341-2

Toutin, T., 1999, Map Making with Remote Sensing Data, Proceedings of the NATO Advanced Research Workshop on Remote Sensing for Environmental Data in Albania: A Strategy for Integrated Management, pp. 65-87

Turner M.G., V.H. Dale, R.H. Gardner, 1989, Predicting across scales: theory development and testing. Landscape Ecology, 3, pages: 245-52

Turk, A.G., 1992, GIS Cogency: Cognitive Ergonomics in Geographical Information Systems, Unpublished PhD thesis, University of Melbourne, Australia

Uitto, J.I., 1998, The Geography of Disaster Vulnerability in Megacities, Applied Geography, Vol.18, No: 1, p. 7-16

Usery, E.L., 2000, Multidimensional Representation of Geographic Features, Proceedings of the XIXth International Society for Photogrammetry and Remote Sensing, Vol. XXXIII, Part B4/3, Commission 4, pp.1092-1099

US National Research Council (NRC) (1989), Improving Risk Communication, Committee on Risk Perception and Communication, National Research Council, National Academy Press, Washington, DC

WMO (World Meteorological Organization), (2002) Guide on Public Understanding and Response to Warnings, WMO, Geneva

Wang F., Z. Xu and K. Feng, 2006, Theoretical Framework of Visualization-based Disaster Digital Simulation, in the proceedings of the 2006 International Symposium on Safety Science and Technology, Changsha, China, Oct. 24-27

Wood, H.O., and F. Neumann, 1931, Modified Mercalli Intensity Scale of 1931, Seismological Society of America, Bulletin 21, 277-83

Wood, J., S. Kirschenbauer, J. Döller, A. Lopes, L. Bodum, 2005, Using 3D in Visualization, In Exploring Geovisualization J. Dykes, A.M. MacEachren, M.-J. Kraak (Editors), published by Elsevier Ltd., pages: 295-312

Wood M. and K. Brodlie, 1994, ViSC and GIS: Some Fundamental Considirations, in Hearnshaw, H. M., and Unwin, D. J., eds., Visualizstion in Geographical Information Systems, John Wiley CycS ons Chichester, p. 3-8

Vanegas C.A. and D.G. Aliaga, 2009, Visualization of Simulated Urban Spaces: Inferring Parameterized Generation of Streets, Parcels, and Aerial Imagery, IEEE Transactions on Visualization and Computer Graphics, Vol. 15, No. 3, May/June

Van Westen C.J., Georgiadou P.Y., 2001, Spatial Data Requirements and Infrastructure for Geological Risk Assessment, Proceedings workshop on natural disaster management, ISPRS Technical Committee VII, Ahmedabad, India

Vinken, R., 1992, From Digital Map Series in Geosciences to a Geo-Information System, Geol. Jahrbuch, A 122: 7-25; Hannover (D)

Visvalingam, M., 1994, Visualization in GIS, Cartography, and ViSC, in Hearnshaw, H. M., and Unwin, D. J., eds., Visualizstion in Geographical Information Systems, John Wiley CycS ons Chichester, p. 18-25

Yalciner A.C., F. Imamura, E.C. Synolakis, 2002, Simulation of Tsunami Related to Caldera Collapse and a Case Study of Thera Volcano in Aegean Sea, EGS XXVII General Assembly, Nice, France, April 2002 Session NH8

Yalciner, A.C., Karakus, H., Ozer, C. and Ozyurt, G., 2005, Short Courses on Understanding the Generation, Propagation, Near and Far-Field Impacts of TSUNAMIS and Planning Strategies to Prepare for Future Events, Course Notes in Kuala Lumpur (METU Civil Eng. Dept. Ocean Eng. Res. Center, 2005)

Yuan L., and H. Zizhang, 2008, 3D Indoor Navigation: a Framework of Combining BIM with 3D GIS, 44th ISOCARP Congress

Zhu Q., M. Hu, 2009, Semantics-based 3D Dynamic Hierarchical House Property Model, International Journal of Geographical Information Science, First Online Published on: 06 November 2008, DOI: 10.1080/13658810802443440

Zlatanova, S., 2000, 3D GIS for Urban Development, PhD Thesis, ITC Dissertation Series No. 69, The International Institute for Aerospace Survey and Earth Sciences, The Netherlands

Zlatanova, S., A.A. Rahman and M.Pilouk, 2002, 3D GIS: current status and perspectives, in Proceedings of the Joint Conference on Geo-spatial theory, Processing and Applications, 8-12 July, Ottawa, Canada, 6p. CDROM

Zlatanova, S., D. Holweg and M. Stratakis, 2007, Framework for multi-risk emergency response, in: Tao&Li (Eds.) Advances in Mobile Mapping Technology, Taylor&Francis, London, ISPRS Book Series, pp. 159-171

Zlatanova, S., 2008, SII for Emergency Response: the 3D Challenges, In: J. Chen, J. Jiang and S. Nayak (Eds.); Proceedings of the XXI ISPRS Congress, Part B4-TYC IV, July 2008, Beijing, pp. 1631-1637

APPENDIX A

ASCII 3D OBJECT REPRESENTATION EXAMPLE

ASCII 3D object representation example, with five faces with four corner points and four different attributes

```
"Shape 111
 Attribute Values:
  0) 94.000000
  1) 0.000000
  2) 34.210000
  3) 823.880000
 Number of Parts: 5
  Part 0
  Number of Points: 5
   0) 30.553544 39.796763 825.594371 0.000000
   1) 30.553542 39.796703 825.594381 0.000000
   2) 30.553680 39.796698 825.592952 0.000000
   3) 30.553682 39.796758 825.592942 0.000000
   4) 30.553544 39.796763 825.594371 0.000000
  Part 1
  Number of Points: 5
   0) 30.553544 39.796763 821.318238 0.000000
   1) 30.553542 39.796703 821.318238 0.000000
   2) 30.553542 39.796703 825.594381 0.000000
   3) 30.553544 39.796763 825.594371 0.000000
   4) 30.553544 39.796763 821.318238 0.000000
  Part 2
  Number of Points: 5
   0) 30.553542 39.796703 821.318238 0.000000
   1) 30.553680 39.796698 821.318238 0.000000
   2) 30.553680 39.796698 825.592952 0.000000
   3) 30.553542 39.796703 825.594381 0.000000
   4) 30.553542 39.796703 821.318238 0.000000
  Part 3
  Number of Points: 5
   0) 30.553680 39.796698 821.318238 0.000000
   1) 30.553682 39.796758 821.318238 0.000000
   2) 30.553682 39.796758 825.592942 0.000000
```

3) 30.553680 39.796698 825.592952 0.000000
4) 30.553680 39.796698 821.318238 0.000000
Part 4
Number of Points: 5
0) 30.553682 39.796758 821.318238 0.000000
1) 30.553544 39.796763 821.318238 0.000000
2) 30.553544 39.796763 825.594371 0.000000
3) 30.553682 39.796758 825.592942 0.000000
4) 30.553682 39.796758 821.318238 0.000000”

APPENDIX B

GENERAL SCALE TSUNAMI ASSESSTMENT

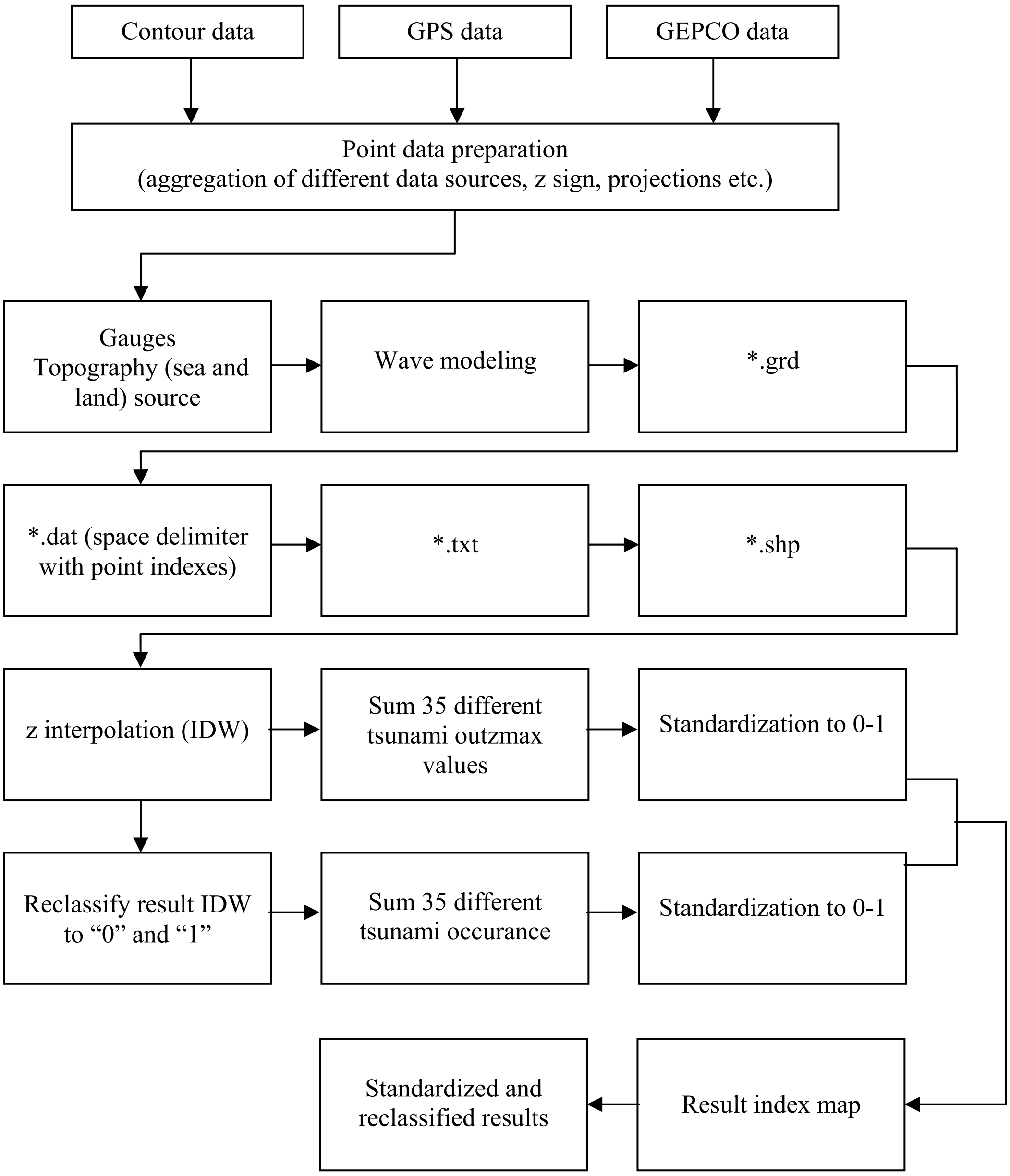


Figure B.1. The workflow of the general scale tsunami assesstment

APPENDIX C

LOCAL SCALE TSUNAMI ASSESSTMENT

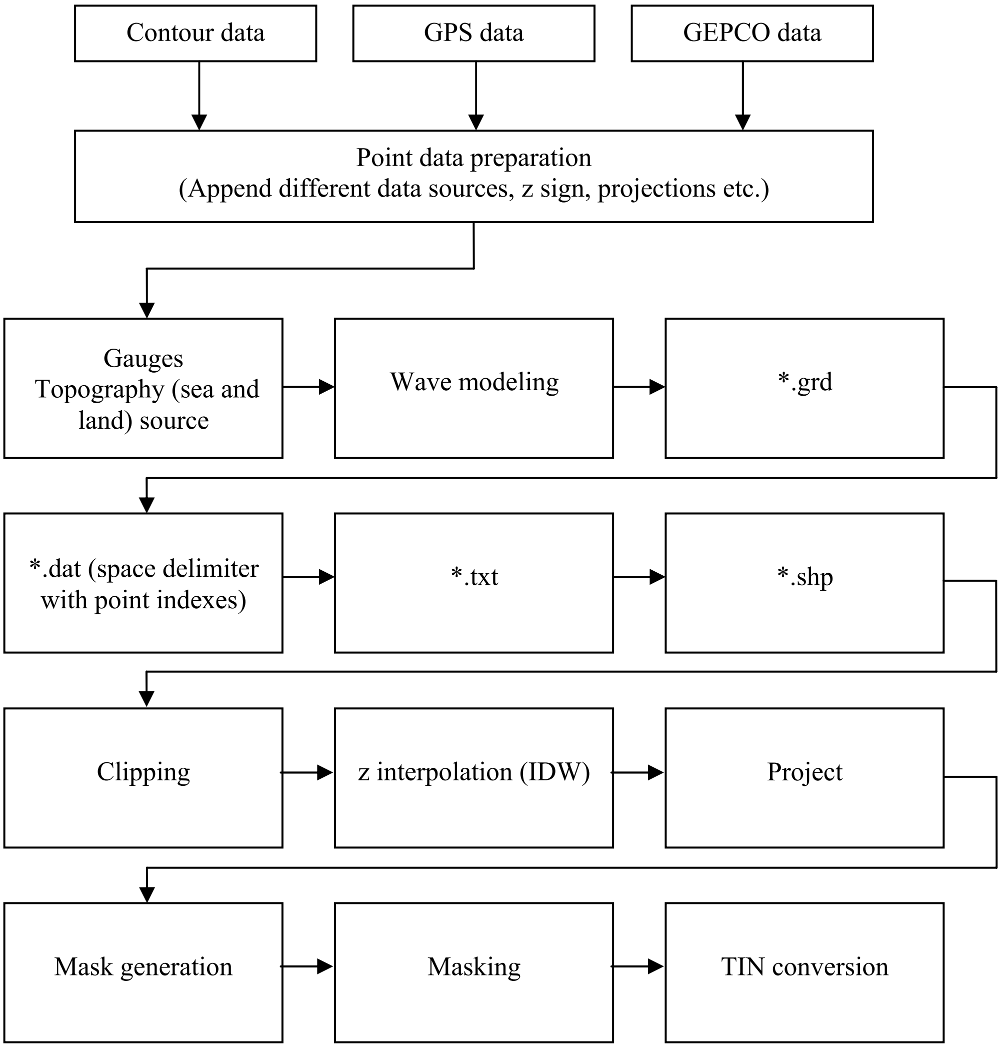


Figure C.1. The workflow of the local scale tsunami assesstment

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name:	KEMEÇ, Serkan
Email:	skemec@gmail.com
Title:	Research Assistant
Nationality:	Republic of Turkey
Date of Birth:	10.04.1978
Marital Status:	Married
Phone:	+90 505 6705767

EDUCATION

Ph.D	Geodetic and Geographic Information Technologies, the Graduate School of Natural and Applied Sciences, Middle East Technical University (METU), Ankara, Turkey	2003 - 2011
B.Sc.	City and Regional Planning, Faculty of Architecture, Gazi University, Ankara, Turkey	1996 - 2001

PROFESSIONAL EXPERIENCE

METU - Middle East Technical University	Research Assistant	2002-Present
Delft University of Technology (TUDelft), OTB Research Institute, Section GIS-Technology	Guest Researcher	2008-2009
BHA Engineering and City Planning Corporation	City Planner	2001-2002
The Ministry of Public Works and Settlement, Housing Development	Intern City Planner	1999
Iller Bank, Development Planning Department	Intern City Planner	1998

FOREIGN LANGUAGES

Turkish (Native - Language), Good command of English

PUBLICATIONS (INTERNATIONAL)

JOURNAL PAPERS

1. Düzgün, H.S.B., Yücemen, M.S., Kalaycioglu, H.S., Celik K., Kemec, S., Ertugay K., Yilmaz N., 2011, An Integrated Earthqake Vulnerability Assessment Framework for Urban Areas, Natural Hazards: Volume 59, Issue 2 (2011), Pages: 917-947 DOI: 10.1007/s11069-011-9808-6

CHAPTER IN A BOOK

1. Kemec, S., S. Zlatanova, and H.S. Duzgun, 2010, "A framework for defining a 3D model in support of risk management", in Geographic Information and Cartography for Risk and Crisis Management, Konecny,

M., S. Zlatanova, B. L. Temenoujka (Eds.), New York: Springer, Pages: 69-83, DOI: 10.1007/978-3-642-03442-8_5

2. Düzgün, H.Ş.B., Kemec, S., 2008, "Spatial Regression and Geographically Weighted Regression for Spatial Prediction" in Encyclopedia of GIS, S. Shekhar and H. Xiong (Eds.), New York: Springer, Pages: 1073-77, DOI: 10.1007/978-0-387-35973-1_1242

3. Thomas D.S.K., Ertugay, K. & Kemec, S., 2006, "The Role of Geographic Information Systems/Remote Sensing in Disaster Management" in Handbook of Disaster Research, Rodriguez, H., Quarantelli, E.L., and Dynes, R. (Eds.), New York: Springer, Pages: 83-96, DOI: 10.1007/978-0-387-32353-4_5

4. Kemec S. and H.S. Duzgun, 2006, "Use of 3D Visualization in Disaster Risk Assessment for Urban Areas" in Lecture Notes in Geoinformation and Cartography Series, Innovations in 3D Geo Information Systems, Alias Abdul-Rahman, Sisi Zlatanova and Volker Coors (Eds.), New York: Springer, Pages: 557-566, DOI: 10.1007/978-3-540-36998-1_43

CONFERENCE PAPERS

1. S. Kemec, H.S. Duzgun, S. Zlatanova, D.I. Dilmen, A.C. Yalciner, 2010, "Selecting 3D Urban Visualisation Models for Disaster Management: Fethiye Tsunami Inundation Case", Incorporatıng the ICA Regional Symposium for Central and Eastern Europe, Third International Conferece on Cartography and GIS, Nessebar, Bulgaria, June, 15-20, 2010

2. Ozer C., D.I. Dilmen, S. Kemec, A.C. Yalciner, A. Zaytsev, A. Chernov, I. Insel, E. Pelinovsky, H.S. Duzgun, 2009, "GIS Based Inundation Mapping, Examples from Mediterranean and South China Sea", South China Sea Tsunami Workshop 3 SCSTW3, in Penang, Malaysia, on 3-5 November 2009

3. Kemec, S., Zlatanova, S., & Duzgun H.S., 2009, "Selecting 3D Urban Visualization Models for Disaster Management: A Rule-Based Approach", The International Emergency Management Society (TIEMS) 16th Annual Conference in Istanbul, Turkey, 9-11 June 2009

4. Kemec, S., Duzgun H.S., & Zlatanova, S., 2009, "A Conceptual Framework for 3D Visualization To Support Urban Disaster Management", Joint Symposium of ICA Working Group on CEWaCM and JBGIS Gi4DM, Cartography and Geoinformatics for Early Warning and Emergency Management, Prague, Czech Republic, 19-22 January 2009

5. Kemec S., Duzgun H.S., 2007, "Analysis of Spatial Variations in Socio-Demographical Variables for 2002 General Elections in Eskisehir by Using SR And GWR", Graduate Summer School on New Advances in Statistics, METU, 11-24 August 2007 (abstract, **best poster presentation award**)

6. Kemec, S., Duzgun, H.S., 2007, "Interoperability in 3D City Models Developed for Earthquake Vulnerability Visualization", XXII International Cartographic Conference (ICC2007), Moscow, Russia, 04-10 August 2007 (Abstract)

7. Kemec, S., Ertugay, K., & Duzgun, H.S., 2007, "Emergency State Health Service Accessibility Visualization in a 3D City Environment", ISPRS Joint Workshop "Visualization and Exploration of Geospatial Data", University of Applied Sciences Stuttgart, Germany, June 27 - 29, 2007

8. Kemec, S. and Duzgun, H.S., 2006, "Use of 3D Visualization in Disaster Risk Assessment for Urban Areas", 1st. International Workshop on 3D Geoinformation 2006 , Universiti Teknologi Malaysia, Kualla Lumpur, Malaysia, August 7-8, 2006

9. Kemec, S. and Duzgun, H.S., 2006, "3D Visualization for Urban Earthquake Risk" in "Geohazards", Farrokh Nadim, Rudolf Pöttler, Herbert Einstein, Herbert Klapperich, and Steven Kramer Eds., ECI Symposium Series, Volume P7 (2006)

PUBLICATIONS (NATIONAL)

CONFERENCE PAPERS

1. Kemeç, S., H.S.B. Düzgün, F. Kulakoğlu, 2010, "Arkeolojik Uygulamalar İçin Düşük Maliyetli 3b Modelleme Yaklaşımı: Kültepe Örneği", Kültür ve Turizm Bakanliği, Kültür Varlıkları ve Müzeler Genel Müdürlüğü, 32. Uluslararası Kazı, Araştırma ve Arkeometri Sempozyumu, Lütfi Kırdar Uluslararası Kongre ve Sergi Sarayı, Harbiye/İstanbul, 24-28 May 2010

2. Kemeç S., Düzgün Ş., 2007, "Deprem Kırılganlıklarının 3 Boyutlu Kent Ortamında Görsellenmesi: Ekişehir Cumhuriye Mahallesi Örneği", TMMOB Harita ve Kadastro Mühendisleri Odası Ulusal Coğrafi Bilgi Sistemleri Kongresi 30 Ekim –02 Kasım 2007, KTÜ, Trabzon, Türkiye

3. Ertuğay K., Kemeç S., Koç San D. ve Özdarıcı A., 2007, "Fiziksel Erişebilirlik Analizlerine Eğimin Etkisi: ODTÜ Yerleşkesi Bisiklet Erişebilirliği Örneği", TMMOB Harita ve Kadastro Mühendisleri Odası Ulusal Coğrafi Bilgi Sistemleri Kongresi 30 Ekim –02 Kasım 2007, KTÜ, Trabzon, Türkiye

4. Kemec S., Düzgün Ş., 2006, "Sosyo-Demografik Yapıdaki Mekansal Değişimlerin, Mekansal Regresyon Teknikleri ile Analizi: Eskişehir 2002 Genel Seçim Örneği", İstanbul Teknik Üniversitesi 1. Ulusal Uzaktan Algılama - CBS Çalıştay ve Paneli, İstanbul, Türkiye