Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2015, Volume 4, Issue 1, pp. 980-989, Article ID Tech-350
ISSN 2320 - 0243

Methodology Article **Open Access**

A Detailed 3D GIS Architecture for Disaster Management

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Publication Date: 16 April 2015

Article Link: http://technical.cloud-journals.com/index.php/IJARSG/article/view/Tech-350

Abstract In order to prevent, avoid or ameliorate the impact of disaster there are various solutions proposed by different international, national organizations, agencies and NGOs. These solutions established GIS as an indispensable tool to develop plans for tackling a disaster in a much better way. Geographic information systems enable efficient organisation of disaster dataset. Its visualization framework are capable to redraw the worst natural clematises that can be quarried and analyzed to produce results, helpful to save important human life and prevent infrastructure damages. Although there is a wide variety of simulation and modelling techniques, implementation strategies and customization options available in GIS, it is impossible to simulate and analyze rapidly changing 3D dynamic disaster phenomena within the current 2D GIS. The perceptions of decision makers tasked with dealing with a particular natural hazard are highly influenced by the manner in which the hazard is visualized. Disaster manager often use digital maps; using 3D graphical representation significantly reduces the cognition effort needed to interpret the situation and improves the efficiency of the decision making process. Automated 3D city modelling is yet an important topic of research, while semiautomatic and manual methods are well developed, applied and already tested for the acquisition of city wide geometry and façade databases. This paper tries to combine the analytical power of GIS in the synchronization with visualization capabilities of 3D Models and brought the most desirable 3D GIS technology for disaster management. This research paper proposes 3D GIS enable disaster management architecture to overcome the current limitations of both 2D GIS and 3D Models in simulating disasters. To respond disaster scenarios 3D GIS architecture cover all phases of 'disaster management life cycle'. Architecture is designed to serve for both the stakeholders and disaster managers for providing better, up to date options that depicts clear and valuable picture of disaster scenarios in all technical dimensions.
Keywords *GIS; 3D GIS; Disaster Management, Risk; Emergency; 3D Model; Disaster Management Life Cycle; Mitigation; Preparedness; Recovery; Response*

1. Introduction

GIS brought a new meaning to geography and its capability to integrate temporal and attribute information helps to explore fresh perspective and hidden meaning in geospatial dataset. Final mapped and tabular results reveal new opportunities, innovative approaches, and ultimately guide planners to achieve sustainable solutions (Tiwari, A. and Jain, Dr. K., 2014). The unique ability to analyze large integrated spatial and non-spatial data with its sophisticated analysis functions 2D GIS proved its importance in many domains, such as urban planning, environmental decision making, landscape design, agriculture and military operations (Zlatanova, Rahman and Pilouk, 2002).

"An unpredictable, unfamiliar, sudden and calamitous impact of a natural, technological accident or an armed conflict that causes an abrupt shock to the intellectual, social, economical, environmental, political and cultural state of the affected area is known as Disaster" (Lindell, Michael K., Carla S. Prater, Ronald W. Perry., 2006). Disaster results a great damage of property, break the growth of the social environment, loss of precious human life and had a bad impact on the development policies of the nation. Disaster Management is the process to make the strategies and plans that directs individuals, groups, and communities to take popper efforts within the scheduled deadlines to avoid, prevent or ameliorate the strength and impact of disasters resulting from hazards (Internship Series., 2007). Disasters are cyclical and by recognizing this, emergency managers, decision makers and planners matches the disaster life cycle with a series of phases that include strategies to mitigate the hazards, prepare for and respond to emergencies and to finally recover from their effects These four phases illustrated in Figure do not always, or even generally, occur in isolation or in this precise order, but instead are integrated with each other phase in a continual evolution.

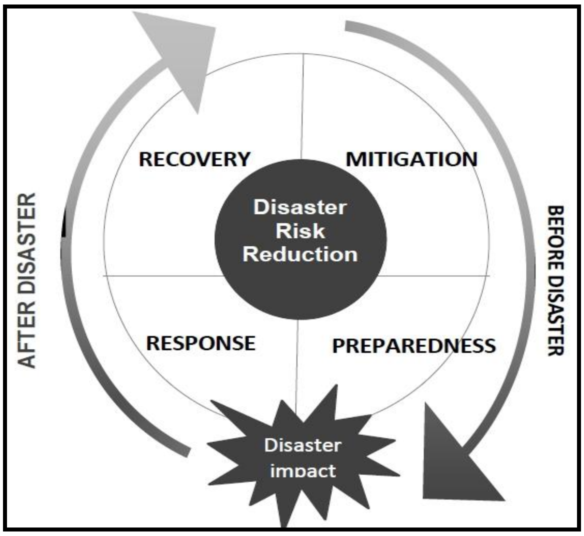

Figure 1: *Disaster Management Life Cycle*

Although there is a wide variety of modelling techniques, implementation strategies and customization options available in GIS, it is impossible to simulate and analyze rapidly changing 3D dynamic disaster phenomena within the current 2D GIS. What are the affected areas? What are the places in danger? Where should be disaster management centre established? Where are rescue centres and relief camps? Where those in danger should be relocated? Without realising concept of third dimension, people often come up with a reply for earlier questions that have 3D component, e.g., 'The upper Himalayan territories of Himachal Pradesh and Uttarakhand are full of landslides', 'All low lying coastal areas can be struck by tsunamis', 'Relief camps are down in the valley', It would be much more illustrative if these answers could be accompanied by 3D Map (Bandrova, T., Zlatanovab, S., Konecnyc, M., 2012). When disaster strikes 3D GIS can be used to fulfil the different levels of data requirement in vulnerability and hazard assessment. In disaster preparedness, it can be a tool for planning evacuation routes, designing centres for emergency operations, and for integration of satellite data with other relevant data in design of disaster warning systems. In disaster response operations, 3D GIS in integration with modern technologies like GPS and IT, extremely useful in search and rescue operations especially in areas that have been devastated. In rehabilitation, 3D GIS is the core technology to redraw a safe and secure city infrastructure.

2. 3D GIS Enabled Disaster Management Architecture

A unified three dimensional visual representation that combine spatial, temporal and attribute information for each and every object of interest and lets us question, analyse, interpret, understand, and simulate data in different ways that reveal hidden relationships, unusual patterns, activities and subtle trends in form of models, globes, maps, reports, and charts is known as 3D GIS. 3D GIS is an advanced technology that combines geospatial data with hardware and software that can analyze spatial, temporal and attribute data to produce important disaster related decision making information and thus this technology prove its vital role in modern emergency management (Kemec, S., Zlatanova, S. Duzgun, H.S., 2010).

Stable and real time data accusation tools like Satellite, Helicopter, Surveillance Cameras, UAV, LIDAR and different on site sensors are used to collect satellite images, Arial photographs, point cloud, site plan, base map or site survey data. To generate the three dimensional or spatiotemporal models from the collected data, data is to be pre-processed and information in three classes (Elevation, Image and feature) is rearranged. These collected Digital Imagery and dimensional information is kept in relational database management system where unimportant and redundant information is omitted. Now filtered information is evaluated to generate facade/ texture dataset and basic geometric model. Level of detail is set according to required depth and by using 3D Modelling library with obtained facade/texture on basic geometric model a detailed 3D model for the underlying area is rendered by 3D GIS Engine.

Immediately after the disaster strikes data is to be collected for both short-term and long-term objectives. Collected data is pre-processed and combined with facade/texture information. Updated facade with immediate disaster information together helps 3D GIS Engine to update already developed 3D model and visualize the impact of disaster at temporal basis. Dynamic information collation is categorized as follows:

- **Real Time Disaster Information:** Real Time disaster information collected from immediate disaster scenario. It helps in easy and quick assessment of calamitous scenario.

- **Near Real Time Disaster Information:** Stable data accusation tools and techniques are used to get near real time disaster information and effect of disaster. This information helps to get the idea of losses and victim's need.

- **High Resolution detailed disaster information:** Stable and detailed data source are used to get complete disaster information which is further assessed to make plan for long term construction, reconstruction and rehabilitation.

3. 3D GIS Engine

3D GIS Engine is the Core working unit of this architecture. Its work is to execute the collected disaster information, compute basic geometric model, update facade/texture information and result view dependent 3D model.

As per the demand of disaster mitigation and management plans 3D GIS Engine has the tools to analyze layered spatial and non-spatial contents. 3D GIS Engine has a definite class of functions; among them a few can be summarised as:

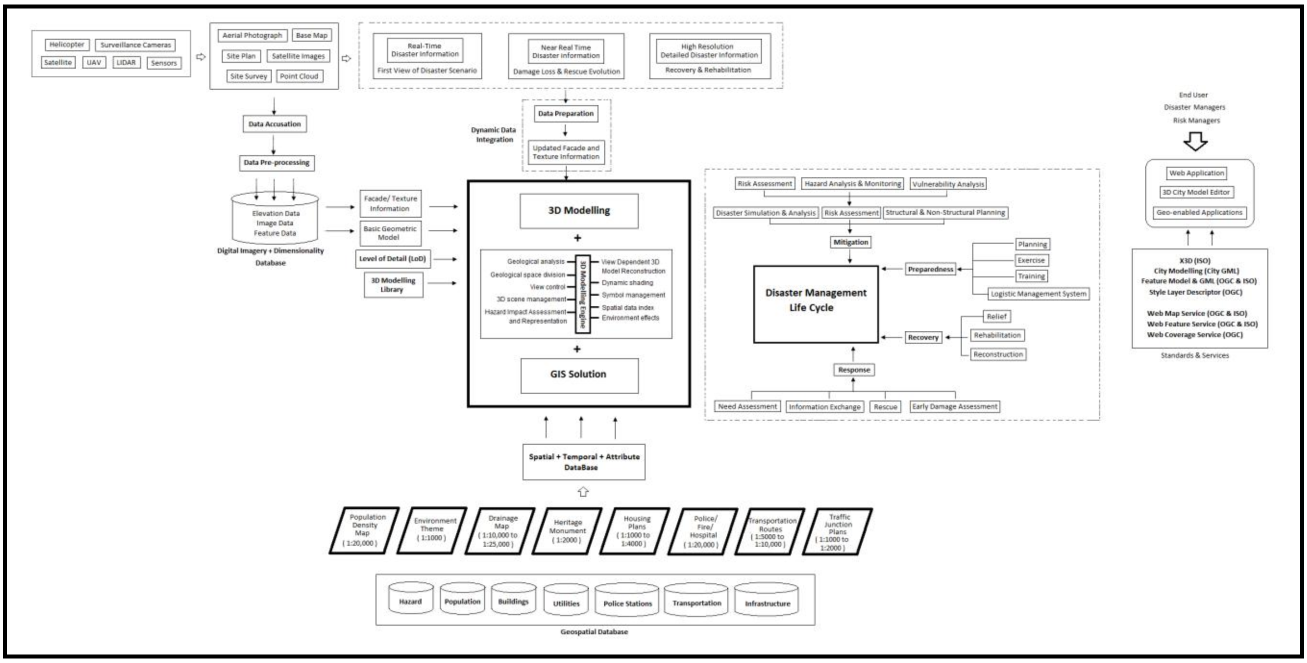

Figure 2: *3D GIS Enabled Disaster Management Architecture*

Geological Space division/ Geological analysis

- View dependent 3D modelling
- View control/ 3D scene management
- Hazard impact assessment and analysis
- Dynamic shading
- Symbol Management
- Spatial Data index
- Environmental Effects

GIS is an integral part of 3D Engine. GIS extends its analysis and visualization capabilities. It helps to keep spatial, temporal and attributes dataset in the form of layers, thematic mapping pertaining to the specific services and requirements in planning and decision making (Stoimenov, L., Milosavljevic, A., Stanimirovic, A.S., 2007) (Tiwari, A., Jain, Dr. K., 2013). Resultant thematic maps enable decision makers to take appropriate action under critical circumstances. Following are the main contents of layered dataset:

- Basic maps, map scale at 1:1,000,000, and partly 1:50,000;
- Urban and Rural area distributions and underlying facilities;
- Social, economic and environmental dataset etc.
- Medical/Educational/Police facilities;
- Road/Rail transportation system;
- Demographic data;

To respond disaster scenarios 3D GIS Engine executes in the phases of 'disaster management life cycle'. The first phase is mitigation where aim is to create a fresh 3D scenario of underlying area/city. Over that simulated virtual environment, risk is calculated by computing underlying affecting parameters like hazard intensity, vulnerability, capacity and city exposure. This is the step where GIS analysis tools are used to overly, define mapped attribute information to calculate expected losses due for a particular hazard; again these expected probabilistic experience is visualized at 3-dimensional platform. Thus an initial disaster prototype model is developed that is used for a basic structural and non-structural planning. Second phase is preparedness where goal is to achieve a certain level of satisfactions in terms of preparation which is sufficient to respond rapidly changing any emergency situations. Preparedness measures include preparedness plans; emergency exercises/training; warning systems; emergency communications systems; evacuations plans and training; resource inventories; emergency personnel/contact lists; mutual aid agreements and public information / education. But main actions start when disaster strikes. Three basic input classes comes into picture in sudden disaster environment and on the time line real time, near real time and detailed disaster information based 3D modelling is done that is used to set disaster response and recovery plan of action with the scheduled deadline. Under these scenario GIS analysis tools worked on underlying disaster information and results are continuously modelled with 3D modelling engine that in turn capable to generate a quick, accurate and detailed virtual disaster scenarios which further can be simulated according to the expert's plan to take necessary relief, rehabilitation and reconstruction action.

Last phase of architecture describes all available services and standards used to deploy 3D GIS enabled disaster management system for its end users, planners, administrators and other disaster stakeholders through various possible platforms like web and desktop. Standards are defined to achieve a universally accepted definition of basic entities, attributes, and relations of a 3D city model. There standards are of prime importance when there is a question of cost effective and sustainable model, allow data reusability across various application domain. CityGML is an open data model and XML-based format for storage and exchange of virtual 3D city models. It is an application schema for Geography Markup Language version 3.1.1 (GML3), the extendible international standard for spatial data exchange issued by Open Geospatial Consortium (OGC) and ISO TC211. WMS (Web Map Service), WFS (Web Feature Service), and WCS (Web Coverage Service) are three web service standards from Open Geospatial Consortium (OGC). These allow web clients to query and receive geographic information in the form of image, vector, or coverage data.

4. Mitigation

An effort to reduce the impact of hazards is known as Disaster Mitigation. It involves pre-event planning and actions which are intended to lessen the impact of a potential disaster as shown in the Figure 3. The essential steps of Hazard Mitigation are hazard identification, risk assessment, defining a hazard mitigation strategy and Implementation of hazard mitigation activities.

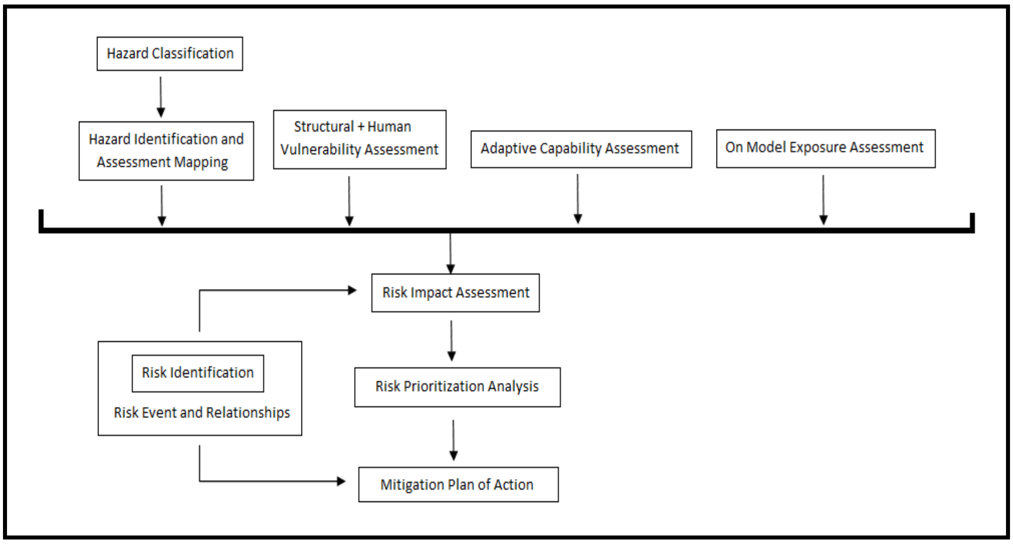

Figure 3: *Framework for 3D GIS based Disaster Mitigation*

Disaster mitigation is an ongoing effort to reduce the physical and social impact of future disasters. It includes interventions made in advance of disasters to prevent or reduce the impact. Mitigation starts with hazard classification and identification so that a detailed mitigation strategy can be developed by getting more and more information about disaster. The classified hazard information is computed with vulnerability, capacity and exposure of the concerned site for risk assessment under 3D GIS framework that is able to give the answer of all associated 'What if ?' questions. Risk event and relationships are prioritized and step by step a mitigation plan of action is developed that will be checked further by having different on model simulation tools available at 3D GIS platform.

5. Risk Assessment

Anticipating potential consequences of disasters can help to determine actions that need to be started before the disaster strikes and reduce the impact of disaster. A comprehensive risk analysis and evaluation create foundation for the development of disaster management plans (Setayesh Barhaghi, M., Kamkar Haghighi, M., Alizadeh, M., 2007). The goal of risk assessment is to provide objectives and transparent information that helps to determine levels of risk and to make decisions that require countermeasures and priorities.

- **Risk (R):** Risk is the expected losses (lives lost, persons injured, damages to property and disruption of economic activity) due to a particular hazard. It is a function of factors for risk assessment (depicted in the figure 4), a relationship that is frequently illustrated with following formula, although the association is not strictly arithmetic:

H * V/C * E = R

- **Hazard (H):** A man-made or a natural event that can potentially trigger disaster s known as Hazard (earthquakes, land-slides, floods, tsunamis, war etc).

- **Vulnerability (V):** Extent of exposure and susceptibility of a community to a hazard. If one is more susceptible/ vulnerable to a hazard the risk of being affected is higher.

- **Capacity (C):** The reverse of vulnerability is capacity, which can be described as the strengths and resources in a community, society or organization to cope with a threat or to resist the impact of a hazard.

- **Exposure (E):** Exposure is the total value of elements at-risk. It is expressed as the number of human lives, and value of the properties, that can potentially be affected by hazards. Exposure is a function of the geographic location of the elements. (Pelling, Mark. et al., 2004).

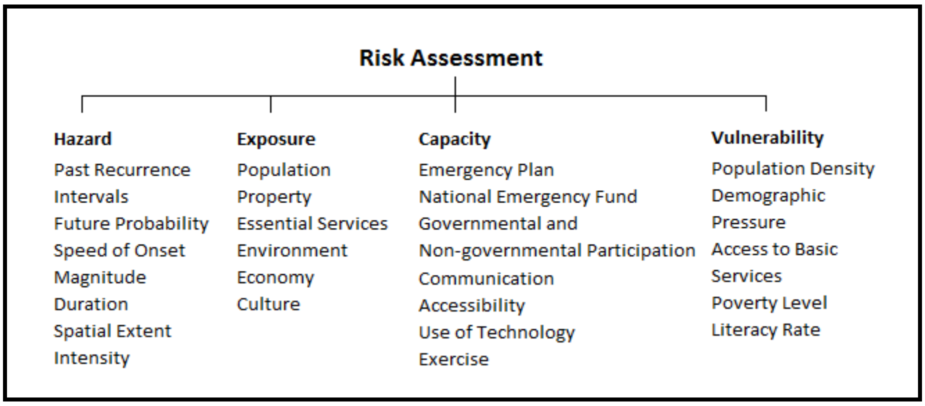

Figure 4: *Various Factors for Risk Assessment*

6. Preparedness

Disasters often strike promptly and without any prior warning. Actions that are taken before emergency to prepare for response and recovery are come under preparedness phase. During this phase different governmental and non-governmental organisations and NGOs contributes in development of plans, finalize the strategies to protect important human lives, reduce infrastructural damage and improve time critical disaster response (Balaji, D., Sankar, R., Karthi, S., 2002). Both on site and off site emergency tactics are developed to have a comprehensive disaster preparation. These plans include hazard forecasting, early warning, relief, rescue and rehabilitation.

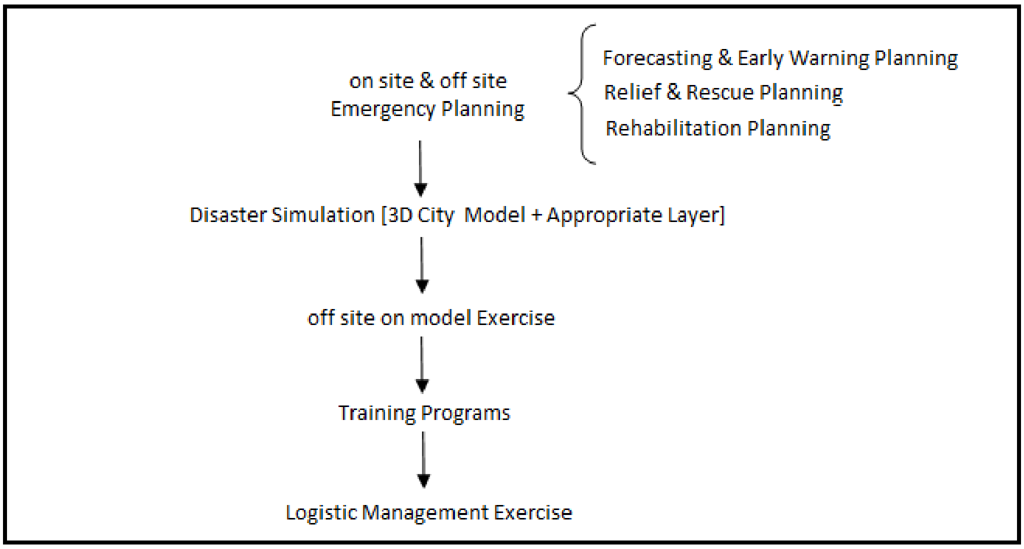

Figure 5: *3D GIS and Disaster Preparedness*

Disaster is simulated with 3D city model and GIS tools, where plans are executed to check their effectiveness. As per the plan different exercise and training programs are planned to train native people and emergency response team are shown in the figure 5.

7. Response

Disaster response includes activities that are required during and immediately after disaster occurs, and are designed to protect life and property and control secondary induced hazards (e.g., earthquake-induced fires and hazardous materials spills). Detailed response plan is mentioned in the figure 6. These actions begin with the warning of an oncoming threatening event or with the event itself if it occurs without warning (i.e. most earthquakes provide no warning).

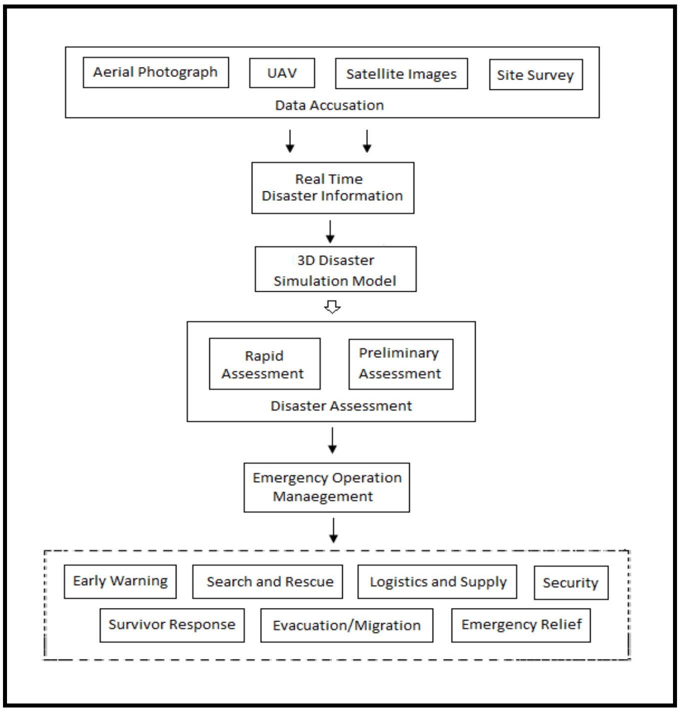

Figure 6: *Disaster Response Activities*

3D GIS has the capability to become an essential emergency response tool. 3D GIS help emergency operators to act quickly and provides them vital information when and where it is needed. Aerial photographs, UAV, Satellites and immediate disaster site survey are possible real time data accusation options in response phase that will further combined with existing site dataset to create an updated 3D disaster simulation model with the layers of various emergency services and scenarios. This 3D GIS based disaster model rapidly evaluated with various assessment tools and an updated emergency operation plan is presented to deal with current calamitous situation. This plan defines the role of different stakeholders and tries to achieve quick event response time that should meet the scheduled deadlines.

8. Recovery

Recovery phase is both short-term and long-term that initiated just after disaster strikes. Actions required to return communities back in their original or near-normal form are come under recovery. Recovery starts with an initial recovery stage to satisfy personal and community needs in tuff disaster scenarios and restores life support services up to a level of control so that government and private agencies collaboration with local people can manage the continuing process (World Urbanization Prospects., 2007). Data Source and various sensor systems for disaster recovery are shown in the figure 7. Long term recovery plans covers reconstruction operations and rehabilitation measures. Complete Recovery phase can be divided into three stages.

- **Initial Stage**: This stage include short term recovery plans for first view of disaster scenario. Here real time disaster information collected from immediate information gathering systems/ locals and short term recovery goals are fixed (Narvaez, R.W.M., 2012).

- **Evacuation and Recovery Stage:** This stage presents a disaster scenario with losses and victim's need. Stable data accusation tools and techniques are used to get disaster information and effect of disaster is tried to reduce with certain deadline.

- **Recovery Phase:** A detailed data source with sensor systems are used to get complete disaster information which is further assessed to develop plan of long term construction, reconstruction and rehabilitation.

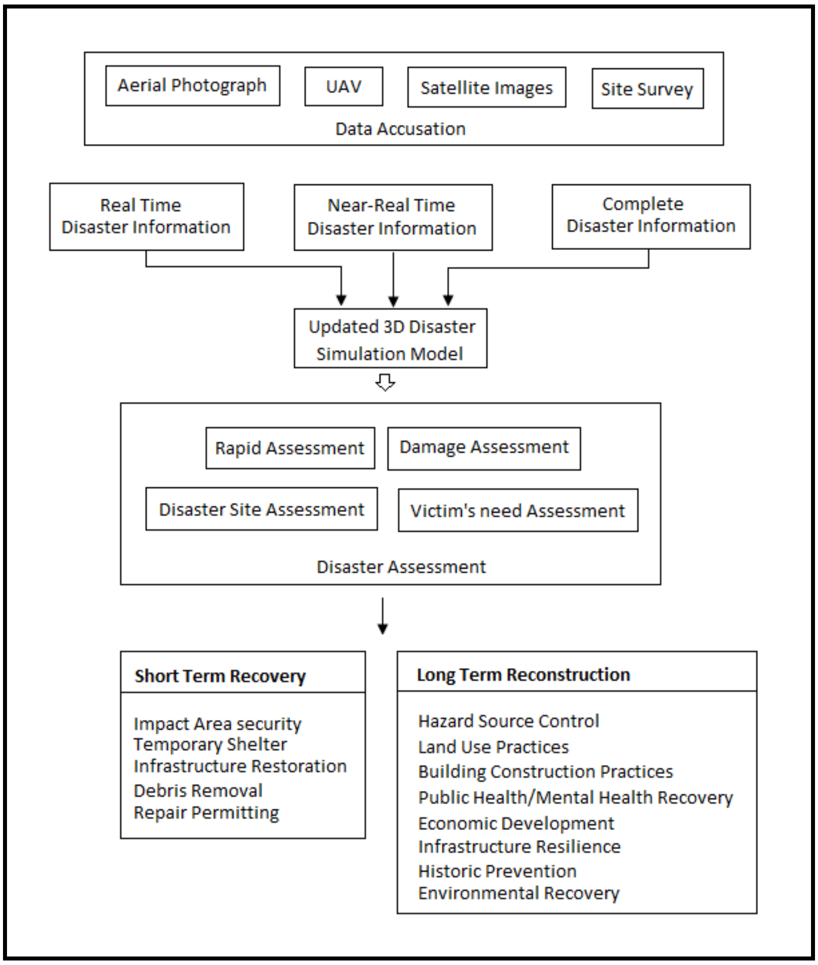

Figure 7: *Data Source with Sensor Systems for Disaster Recovery*

9. Conclusion

The successful use of 3D GIS in disaster management is yet an important area of research. Disaster management essentially require 3-dimensional geo information from different sources and sensor systems that have to be integrated together to improve monitoring, reduce damage and facilitate better estimates of damages and losses. In this paper we presented a complete architecture for 3D GIS based disaster management system development. Every possible way of information gathering with scenario specific classes are defined that through their specific interfaces provide data for 3D modelling Engine. Comprehensive workings of 3D engine in integration with specific GIS layers are discussed. This architecture also focus on every phase of disaster management life cycle and in depth finalize complete system in all possible format (web, desktop, editor) with their corresponding standard and services. Current study evaluates 3D GIS on well-defined principles of emergency management that proved 3D GIS as most suitable platform for disaster management and mitigation system development in future.

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