Web Based Spatio-Semantic Analysis of Traffic Noise Using 3D Geospatial Information

Thesis submitted to the Andhra University, Visakhapatnam in partial fulfilment of requirement for the award of *Master of Technology in Remote Sensing and GIS*

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DISCLAIMER

This document describes the work undertaken in partial fulfillment of Masters of Technology program in Remote Sensing and Geographic Information System at Indian Institute of Remote Sensing, Dehradun, India. All views and opinions expressed therein, remain the sole responsibility of the Author, and do not necessarily presents those of the Institute.

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Certificate

It is certified that the dissertation entitled ***"Web Based Spatio-Semantic Analysis of Traffic Noise Using 3d Geospatial Information"***, has been carried out by ***Mr. Amol Konde*** in partial fulfilment of the requirements for the award of ***M. Tech. in Remote Sensing and GIS***. This work has been carried out under the supervision of ***Dr. Sameer Saran***, Scientist 'SF', Geoinformatics Department, Indian Institute of Remote Sensing, ISRO, Dehradun, Uttarakhand, India.

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Declaration

I, ***Amol Konde***, hereby declare that this dissertation entitled ***"Web Based Spatio-Semantic Analysis of Traffic Noise Using 3D Geospatial Information"*** submitted to Andhra University, Visakhapatnam in partial fulfilment of the requirements for the award of ***M. Tech. in Remote Sensing and GIS***, is my own work and that to the best of my knowledge and belief. It is a record of original research carried out by me under the guidance and supervision of ***Dr. Sameer Saran***, Scientist, 'SF' GID, Indian Institute of Remote Sensing, Dehradun. It contains no material previously published or written by another person nor material which, to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Place: Dehradun Mr. Amol Konde

Date:

Dedicated to my Parents,

Brother Ashwin

And Sister Mamta

Abstract

The study blends the innovations in computer technologies to ensure modeling of urban geospatial environment for simulation and analysis at different semantic level of details. Visualization and analysis in 3D at different level of details enables realistic simulation and prediction of physical and geospatial phenomena. Moreover, with latest trends and innovations in computer technologies 3D visualization is now becoming the reliable and more interactive mode of visualization. 3D technologies have been adapted in various disciplines of engineering and social sciences, media and communication. The most recent applications of 3D city model include simulation of urban energy demand, facility management, city planning and architectural simulation, geospatial mapping of climate and environment, flood simulation etc. Traffic noise mapping is one of the areas where the present research identified the utility of 3D city modeling to be very effective. India is one of the most populated countries in the world and with this increased population it poses environmental and management risks like increased traffic. The traffic noise is the primitive contributor to the overall noise pollution in urban environment. So, it is essential for urban planners to meet the needs of innovative solutions in context of traffic noise simulation based on virtual 3D city models. Requirement of applications vary from simple to detailed 3D city models depending on the input data and analysis to be performed. So, to meet this requirement 3D data acquisition is managed through five discrete semantic level of details (LoDs). There are two aspects, geometry and semantics of a 3D model, that are essential for analysis. For the present work geometric aspect has been achieved using the geometric modeling softwares like Google Sketchup, ESRI CityEngine etc. and for semantics, a City Geographic Markup Language (CityGML) was utilized. A 3D model components developed in Google Sketchup, were grouped and carefully assigned geometric attributes to enable its export into CityGML (OGC encoding standard) which was again loaded into PostGIS for further analysis. A web based GIS framework was implemented for analysis of traffic noise pollution and simulation of noise level mapped on building walls. To integrate the results of analysis with CityGML, existing CityGML classes were extended to support the attributes of 3D traffic noise mapping using the process of City GML Application Domain Extension (ADE). A UML class diagram was developed and transformed into an xml schema which serves as a contract between heterogeneous applications for interoperability through validation of instance documents. The presented research work is an open source infrastructure for analysis of 3D City Models and it can be utilized by urban planners for making right decisions before implementing the plan.

Keywords: Traffic Noise Modeling, Level of Detail (LoD), Semantic Analysis, Interoperability, CityGML, Application Domain Extension (ADE)

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List of Abbreviations

3D GIS	Three Dimensional Geographical Information System
3DCityDB	Three Dimensional City Database
ADE	Application Domain Extension
BIM	Building Information Modeling
CityGML	City Geography Markup Language
GML	Geography Markup Language
ISO	International Organization for Standardization
JSON	JavaScript Object Notation
Leq	Equivalent Sound Level
OGC	Open Geospatial Consortium
SCM	Standard Calculation Methods
UML	Unified Modeling Language
VLSM	Virtual Sound Level Meter
Web GIS	Web Geographical Information System
Web GL	Web Graphics Library

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CHAPTER 1

INTRODUCTION

Initially in 1980s, the CAD system made it possible to transform the maps into digital format. Later the advancement in computer analysis and manipulation capabilities led us to Geographic Information System (2D GIS) where it was possible to apply analysis operations along with topological operations. But 2D GIS has many limitations for the cases where analysis in 3D or photo realistic simulation is essential in some application like facility management, energy demand simulation, green building design, solar potential estimation of the buildings etc. This gave rise to an innovative field of 3D GIS which is in continuous research and development stage in all of its phases including data collection techniques, representation models of 3D geospatial information, 3D geospatial information support in spatial databases for storage, 3D manipulation and analysis functions, 3D data rendering and visualization techniques.

Twenty first century technological advancements like internet and quick transport and so on lead this world into globalization, economic growth, higher standard of leaving and many more benefits. These advancements additionally prompt issues like pollution and environmental imbalance which need to be addressed and controlled over the course of time. Green city concept is one of such major steps in this respect. With Remote sensing and GIS technologies we could find the solutions of many of the green city problems. Smart city services that make the citizens aware of the live situations and help them to take certain decisions that make up the smart city, are very important. New applications based on 3D modeling such as virtual reality, 3D GIS and urban simulation are currently in development stage with very rapid improvements. Web GIS technology is evolving fast to implement web services that support various scientific applications using semantic 3D city models for analysis. With 3D city modeling more and more realistic view has been given to these smart services. To enable collaboration in this heterogeneous environment with independent developments, standardized data exchange methods for city models comprising both spatial and semantic information are required (Rafika, 2013). Open Geospatial Consortium (OGC) with contributors from variety of areas like research, academia and industry, are taking the responsibility for standardization of geospatial information and services among all the organizations working in this area. OGC is a nonprofit, international standards organization that is leading the development of standards for geographic data related operations and services (Sayar et al., 2005). OGC formed Open Geographic Information Systems (OpenGIS) is responsible for the development of geo-processing interoperability (Sayar et al., 2005).

1.1 Background

Representation of real world 3D objects in an abstract 3D spatial data model is the current focus of 3D GIS vendors and research institutions. An ideal 3D spatial data model has geometric and topological structuring, and supports attributes for manipulation and semantic information. Functions of a GIS system are to: 1) capture, 2) structure, 3) manipulate, 4) analyze, and 5) present geospatial information (Raper, 1992). Current 3D GIS vendors does not provide a total solution to all these functions. Some of the latest efforts by GIS communities like OGC are focusing on major aspects of 3D GIS systems like data structures and data models.

Voxel data structures (Jones, 1989) were the focus point of most of the previous work on 3D data modeling. This data modeling approach only supports geometric operation and does not support topological operations which are an essential component of spatial data modeling. Another modeling approach by Carlson (1987) also called the simplicial complex. In this approach the terms 0-simplex, 1-simplex, 2-simplex, and 3-simplex are used to denominate spatial objects node, line, surface, and volume. Cambray (1993) has proposed a combination of Constructive Solid Geometry (CSG) and Boundary representation (B-rep) as a way to create 3D GIS. Many more attempts were made to provide a 3D GIS solutions during the 1990s (Abdul-Rahman and Pilouk, 2008). The current trend is moving towards semantic information modeling. The Simplified Spatial Model (SSM) (Zlatanova and Tempfli, 2000), follows the object paradigm and is strictly defined using set theory notions (see Zlatanova 2000) to support topological operations. SSM distinguishes four geometric objects (point, line, surface, body) and two constructive objects (face and node) and each geometric object can be associated with thematic information. (Zlatanova and Tempfli, 2000). All the geometric models having lack of thematic support have limited utility. To expand its utility, support for semantic information modeling for different themes is essential. OGC has recently proposed CityGML as the solution to this need (Stadler and Kolbe, 2007).

1.2 Motivation and Problem Statement

1.2.1 Geospatial Information Interoperability

GIS is currently in continuous state of transformation and many research, commercial organizations and academic institutions exchange geospatial information. The geospatial information comes in the form of vector or raster data mostly pertaining to terrain features or urban features like buildings, roads, bridges, tunnels, rivers etc. These features are dynamic in nature so the exchange of information is a necessary and important constraint of this technology. Currently web services are very much evolved and adapted to the exchange of 2D geospatial information but the requirement for exchange of 3D geospatial information is still in development stage. Some solutions have been proposed recently to share 3D geospatial information across Internet through geospatial web services (Scianna and Ammoscato, 2010). The exchange of geospatial information must be standardized to engage itself in a structured and automated process of data flow and analysis. An interoperable way of data representation is the solution to this problem and Open Geospatial Consortium is continuously working in this area to achieve this goal.

1.2.2 Internet and GIS

Existing GIS vendors provide desktop based GIS solution for manipulation and analysis of 3D geospatial information and also these solutions (or softwares and tools) are mostly proprietary. Some open source solutions are being proposed but these are still in research or not accessible due to lack of awareness or these are restricted to limited number of people. Internet being accessible to all and easily approachable can be utilized as a solution to all these problems but the available web based GIS solution does not offer full 3D GIS functionality in terms of geometric and topological structuring, manipulation and analysis of 3D geospatial information.

To manage all the disciplines under a common centralized GIS model is one of the greatest requirements of a 3D GIS enterprise application and the concept of 3D city modeling has been discussed for this purpose. To achieve this goal the system has to be capable of visualizing the 3D city model at different scales. These different scales are generally termed as semantic level of details. The integration of semantic information with these centralized models gives an advantage of utilizing the same city model for different applications at different semantic levels. Henceforth an open source web based solution for the geometric and topological modeling of 3D geospatial features and manipulation and analysis at semantic level is necessary to provide optimum solution to a GIS problem.

1.2.3 User Applications

The GIS is a platform that facilitates integration of semantic and geometric data, and spatial relationships, providing an appropriate system ensuring a large scope of analysis to serve small scale to large scale applications (Zlatanova et al., 2002). Today the world as it is moving towards a highly accurate and advanced infrastructure and services, needs very careful utility of energy and resources due to climate change and scarcity of available resources. A 2D GIS system has limitations when it needs a realistic model of the world to simulate and analyze a geospatial phenomenon. As the buildings in urban areas are higher and these undergo continuous reforms so a facility management application, site planning of monuments, 3D traffic noise mapping and urban block capacity estimation etc. these are the scenarios when a 2D GIS system cannot provide a realistic solution as the world we live in is 3D. Hence a 3D GIS system with 3D model having embedded semantic information can solve the problem hence there is an increasing need for 3D geo-referenced information and a 3D GIS system for manipulation and analysis of this information.

1.3 Research Identification

3D GIS systems are continuously evolving to support more thematic information with improved support of topological operations and this technology is still in its research phase. It has been observed that the 3D GIS solutions are being provided by many independent commercial vendors which pose an interoperability problem due to heterogeneity among these systems. There are many geospatial phenomena that are also temporal in nature. Traffic noise emission and propagation was identified as one of such phenomena. It has been observed from literature review that there is no commonly agreed interoperable standard for exchange of temporal information along with 3D geospatial data. OGC has proposed CityGML as the standard for the information exchange and it has been widely used among many vendor applications. So CityGML was identified as the standard for representation and semantic analysis of 3D geospatial information.

1.3.1 Research Objectives

The primary objective of the research work is an implementation of a web based open source enterprise solution for spatio temporal visualization and analysis of 3D vector data.

1. Design and implementation of a web based GIS application for visualization and analysis of the 3D city model.
2. To develop a process for collection and reconstruction of 3D Vector Data in context of CityGML Sematic level of details.
3. Develop a simple Traffic Noise Model for roads in the study area using road traffic data and attributes.
4. Spatio-semantic analysis for quantification and mapping of traffic noise levels.
5. Conceptual schema development for integration of analysis results into CityGML data model for interoperable exchange among varieties of systems.

1.3.2 Research Questions

1. What are the open source technologies that fits the requirement of the proposed 3D GIS solution?
2. How to integrate the collected geometric information to form an interoperable 3D data model?
3. How to assess the traffic noise model to be used for the roads in the study area?
4. What are the different cases that should be considered for analysis to match the requirements of the people living along the roadside?
5. How the create an application specific conceptual schema extending the existing schema for CityGML?

1.4 Thesis Outline

The thesis is divided into seven chapters (including first chapter of introduction) as follows,

Chapter 1: This chapter is an introduction of the document. It provides a background of the thesis, motivation behind the selection of this work, the objectives proposed and the issues faced to complete these objectives.

Chapter 2: This chapter lists the hardware and software tools utilized during this project work and also presents a 2D map of the study area.

Chapter 3: This chapter presents the different strategies that can be applied for 3D model reconstruction and also presents the procedure proposed and implemented for the 3D model reconstruction of the study area.

Chapter 4: This chapter reviews the different traffic noise models and presents a proposed traffic noise model developed using statistical regression modeling approach.

Chapter 5: This presents the design and implementation of the web GIS enterprise solution for storage, spatio temporal analysis and visualization of 3D geospatial information.

Chapter 6: This chapter presents the process followed to generate a thematic schema for proposed CityGML application domain extension.

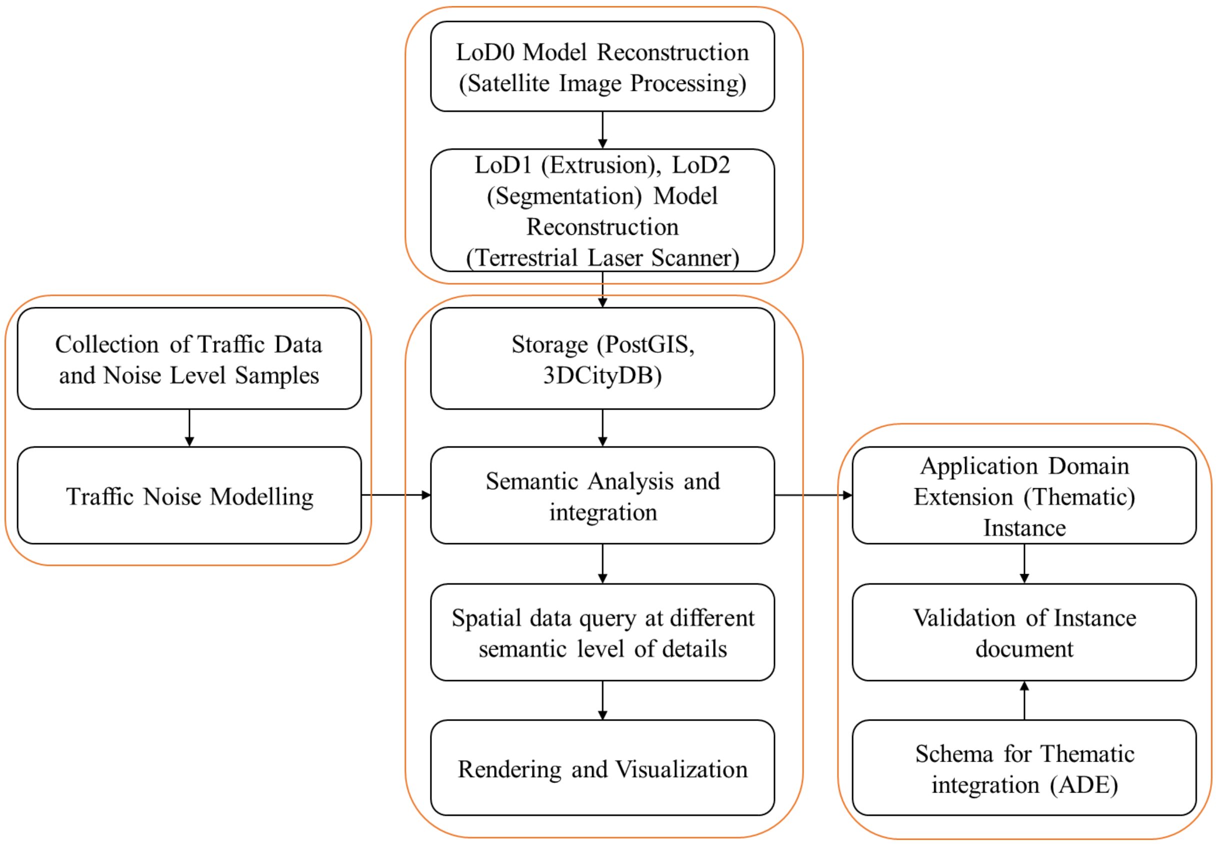

Figure 1.1 Outline of the thesis

CHAPTER 2

MATERIALS AND METHODS

2.1 Study Area

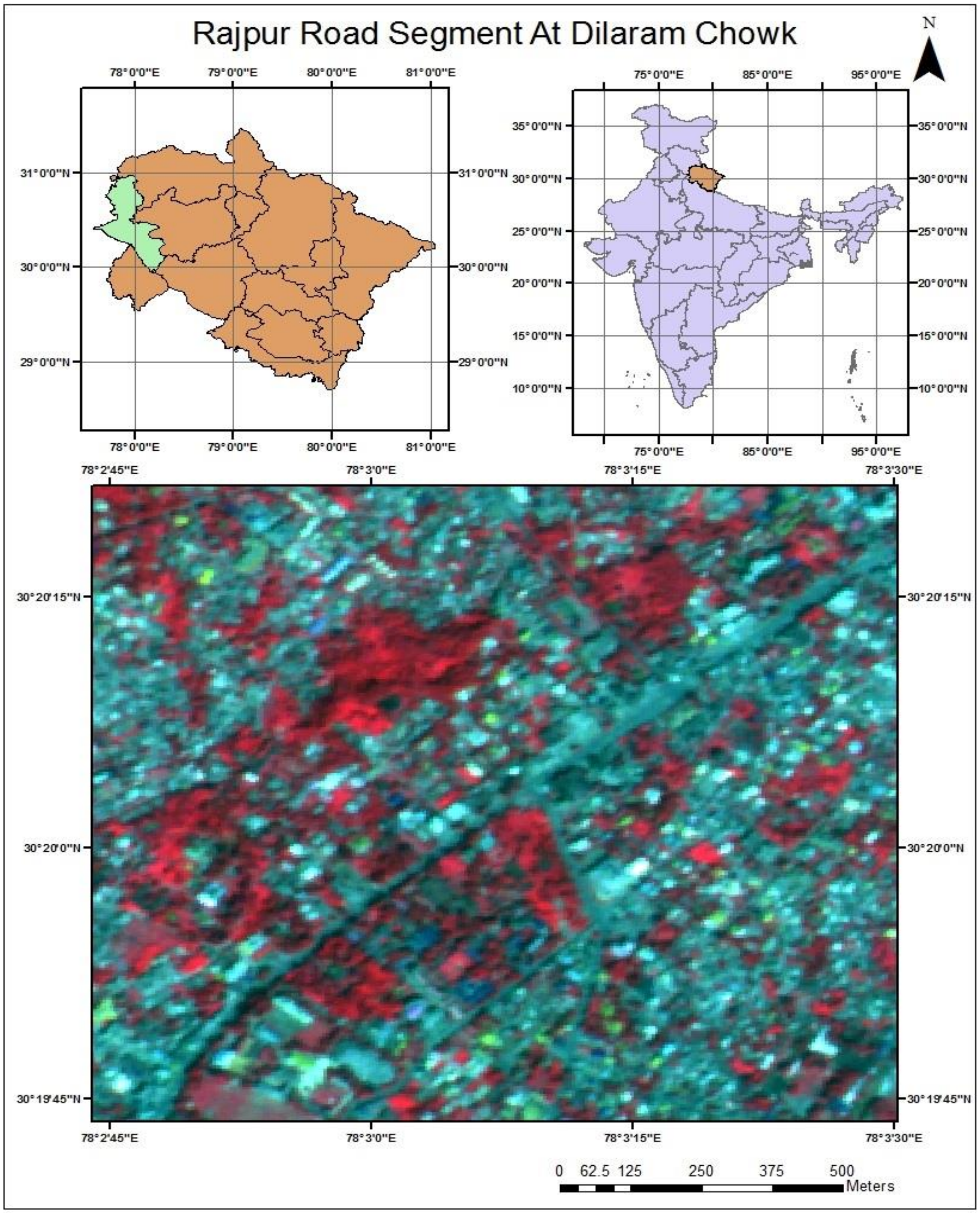

Figure 2.1 Study Area in a LISS-IV Imagery

For traffic noise modeling, multiple observation points were collected at two of the busiest routes in Dehradun. The first one is Saharanpur road which is a national highway (NH 72A) that connects Dehradun to Saharanpur and the other one is the Rajpur Road that connects Dehradun to Mussoorie which is the mostly preferred tourist place in the region. For 3D Model Reconstruction, visualization and analysis, Dilaram Chwok on Rajpur Road and its surrounding region bounded between 78° 2' 55.4532" to 78° 3' 18.5328" East longitudes and 30° 19' 50.124" to 30° 20' 12.732" North latitudes was selected.

2.2 Software and Hardware Tools

2.2.1 Software Tools

Table 2.1 Software Tools Used

Tool	Utility
ESRI ArcGIS 10	Map Composition, 3D geospatial Analysis
Riegl Riscan Pro	Point Cloud Data Processing
Google SketchUp 8	For 3D Modeling of the study area.
CityGML Google Sketchup Plugin	For transformation to CityGML
R version 3.1.2	Statistical Analysis and Modeling
FZK Viewer 4.1	To view CityGML Datasets
ESRI CityEngine	To model and view 3D datasets
Enterprise Architect 9	To model UML Class Diagrams
ShapeChange 2.0.0	To generate XML Schema from XMI files
Notpad ++	For Validation of XML Schema files
PostGIS 2.1.3	To store and manage 3D geospatial information
Cesium Javascript Library	Visualization and Analysis of geospatial information
Eclipse Luna	Web Development
Virtual Sound Level Meter 0.4.1	Audio data processing for noise level estimation

2.2.2 Hardware Tools

Table 2.2 Hardware Tools Used

Tool	Utility
Riegl VZ-400	Point Cloud Data Collection
Sony Xperia SP	For Audio Recording of traffic noise

CHAPTER 3

INTEROPRABLE 3D MODEL RECONSTRUCTION

3.1 3D Data Representations

The attributes for visualization of any 3D model can be generally divided into three parts that is geometry, appearance and scene. The geometry is always stored as a set of 3D points. These points (or vertices) can be combined to form lines, polygons and other geometries. Many models have been proposed in past for an efficient 3D data representation. 3D Object representations are classified as surface-based and volume based (Li, 1994). In surface-based representations, object is represented by any of the surface primitives like are grid, shape model, facet model, and boundary representation (b-rep) etc., whereas, volume-based representations are 3D array, 3D TIN (or TEN), octree, constructive solid geometry (CSG) etc. Boundary representation (B-rep) assumes point, edge, face and volume as representation primitives and defines objects as a combination of these primitives. In boundary representation surface is represented as a set of faces and the number of vertices in the face can vary from two in case of lines, three in case of triangulated surface or more (McHenry and Bajcsy, 2008). Boundary representation model represents an object in the form of a mesh to form boundary of the object (Murali and Funkhouser, 1997). It also defines the topological relationship among faces of a solid object making it a closed space in 3D environment. One of the disadvantages of B-rep is that, to represent non-planar surfaces, functions like B-spline that are very complex and computationally expensive has to be utilized.

A 3D spatial model is an aggregate of geometric and topological model. In recent years, many topological models have been proposed based on the above mentioned data models such as Tetrahedral Network (TEN), Urban Data Model (UDM), and Simplified Spatial Model (SSM) etc. (Sakkalis et al., 2000; Vivoni et al., 2004) etc.

3.2 CityGML

The modeling and analysis of 3D space at semantic level including aboveground and underground, indoor and outdoor environment is necessary to offer an optimum total solution (Zang et al., 2011). 3D City Models are gaining more and more popularity in geospatial modeling and mapping domain as these provide various advantages for many dynamic user applications. These are shared among various tools and applications which can apply different approaches and work on different formats for analysis. Every approach has certain advantages and disadvantages for specific applications. To utilize the same city model within these different applications an interoperable and platform independent representation format is a necessary requirement. An interoperable data model can be easily generated from and converted to other data models. CityGML has been proven to be the solution to this issue.

The degree of data quality required for any city model depends on its intended application and the data collected for that application. This requirement of different levels of data quality must be reflected by the concept of different Level of Detail (LoD) (Joachim et al., 2013). CityGML is a semantic information model that supports the same object representation in different LoD simultaneously, enabling the analysis and visualization of the same object with regard to different degrees of resolution. Also, two CityGML data sets containing the same object but in different level of detail may be combined and integrated. (Gröger and Plümer, 2012).

3.2.1 Level of Details

In CityGML five LoDs are defined, which mainly distinguishes the amount of detail of building exteriors. The building footprints of the 3D model correspond to available building footprints from key registers or site plan etc. whereas, LoD1 is characterized by simple extruded buildings, LoD2 buildings mainly differ from LoD1 buildings by the fact that, InLoD2 also simplified roof structures are modelled. CityGML LoD2 models can now-a-days be created relatively easily using airborne laser altimetry (Vosselman and Dijkman, 2001). LoD3 buildings are true architectural models. Only LoD4 contains building interiors with a lot of detail, which is how it LoD4 differs from LoD3. Therefore building interiors always have to be in the same LoD.

1. LOD0: This is the basic and coarsest level of representation and is considered as a 2.5D Digital Terrain Model (DTM). The foot print polygons of urban features like buildings generated from the ortho-imagery are draped over the terrain to create the 2.5D representation model.
2. LOD1: This is a well-known blocks model, without any roof structures. This level is used for city and region level coverage. This model is useful for representation and analysis over a large area.
3. LOD2: This level has distinctive roof structures and larger building installations like balconies and stairs. This level of detail is suitable for district/city level projects.
4. LOD3: This is the highest level of representation for external features of the urban objects. It denotes architectural models with detailed wall and roof structures, doors, windows and bays etc.
5. LOD4: This completes a LOD3 model by adding interior structures like rooms, stairs, and furniture.

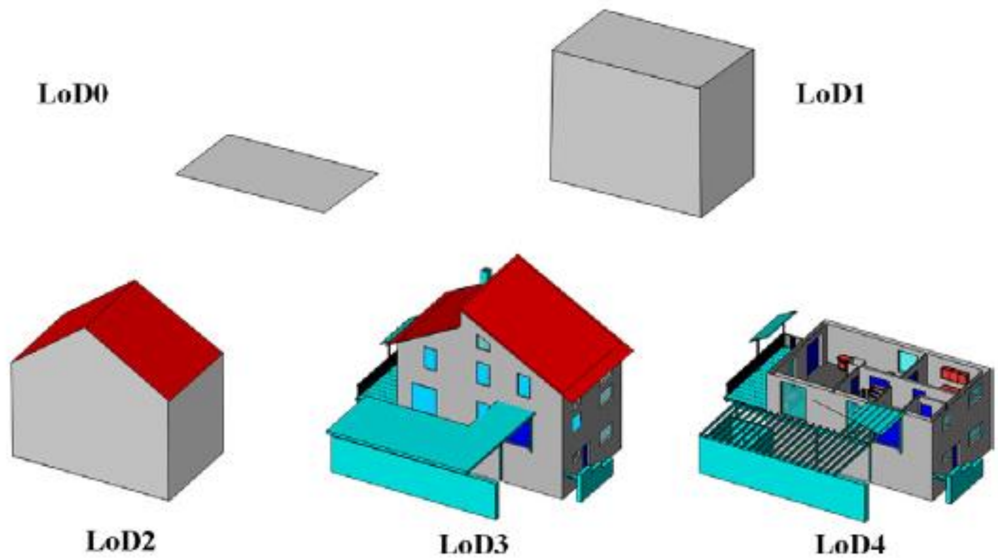

Figure 3.1 CityGML Levels Of Details (Gröger and Plümer, 2012)

3.3 3D Geometry Reconstruction Techniques

Many techniques are adapted for reconstruction of 3D geometry. The choice is based on the application and the level of accuracy and details required. The techniques vary from time consuming field survey and data collection for the geometric attributes using survey instruments like total station to fast and accurate laser scanning. Also, stereo imaging is one of the emerging technique for the 3D model reconstruction of the large urban areas.(Alcantarilla et al., 2013; Koch, 1995; Se and Jasiobedzki, 2008)

Currently the laser scanning techniques are adapted more and more as these provide very fast and detailed collection of data also the colored laser scanning is evolving very rapidly in the market. Photo-Realistic 3D models are very useful for in various applications such as gaming, military applications, mining, forensics, archaeology, virtual reality, etc. So the data acquisition and processing of the 3D point cloud and its color or texture information has been an area of research and development for many years. (Lin, 2002).

The Methods of 3D geometry reconstruction of objects can be broadly divided into two types, Passive sensing techniques that require standard image capture devices such as passive sensors mounted on satellites, photo-cameras, or video-cameras for 3D reconstruction and active sensing techniques such as those based on laser range scanning or light pattern projection that tend to be more accurate but more expensive and slower than passive sensing techniques.(Brusco et al., 2005)

3.3.1 Laser Range Scanning

Laser scanning provides speed, accuracy ad very high resolution which is essential for detailed model reconstruction. The laser scanners exist in short and long range starting from few centimeters to several meters covering a large sized scenes. It can be used to scan both interior and exterior of the buildings so is one of the best technique for LoD4 model reconstruction. Laser scanning has become an industry standard for reconstruction of archeological sites, historical buildings and monuments. The process of 3D model reconstruction using the Laser scanning requires to go through following steps. (Kordelas et al., 2010)(Lin, 2002)

1. Laser scanning of the scene to acquire the adequate point cloud to cover the whole scene
2. Pre-Processing: Merging of multiple scans using tie points and registration to the same coordinate system, Resampling, Filtering, Multi-station adjustment etc.
3. 3D Model Reconstruction: Surface Integration and Construction of a 3D model comprising polygonal facets.
4. Texturing: Texturing gives photo-realistic view to the 3 Model generated.

3.3.2 Stereo Reconstruction

Stereo vision makes it possible to estimate 3D scene geometry given only two images from the same scene. Alcantarilla et al., 2013 a method of dense 3D reconstruction of large-scale environments using stereo imagery from a moving platform. Also (Se and Jasiobedzki, 2008) proposed a tool to create 3D models from a mobile hand-held stereo camera. Many other methods are being proposed and adapted for the reconstruction using stereo images and this approach is still in research and development stage.

3.4 3D Model Reconstruction of Study Area

3.4.1 Data Acquisition

The strategy to be applied for the data acquisition is based on the area to be scanned, the number of scans required. The selection of scan positions is a trivial as it affects the accuracy of scan to scan registration. There are many methods for scan to scan registration some of these are automatic feature matching procedures while some require the selection of markers for registration (Kordelas et al., 2010).

The requirement of the work was to create an approximate LoD1 or LoD2 model of the study area and to achieve this goal the number of scans required at each site were limited to three scan positions. The point cloud data was collected at five different sites using the terrestrial laser scanner (Riegl VZ-400) with spatial resolution of 0.25 meter. For each scan minimum five tie points were created and these tie points were utilized further to merge all the scans together. The single color view and realistic view (colored laser scan) of a building in the study area is shown in fig. 3.2,

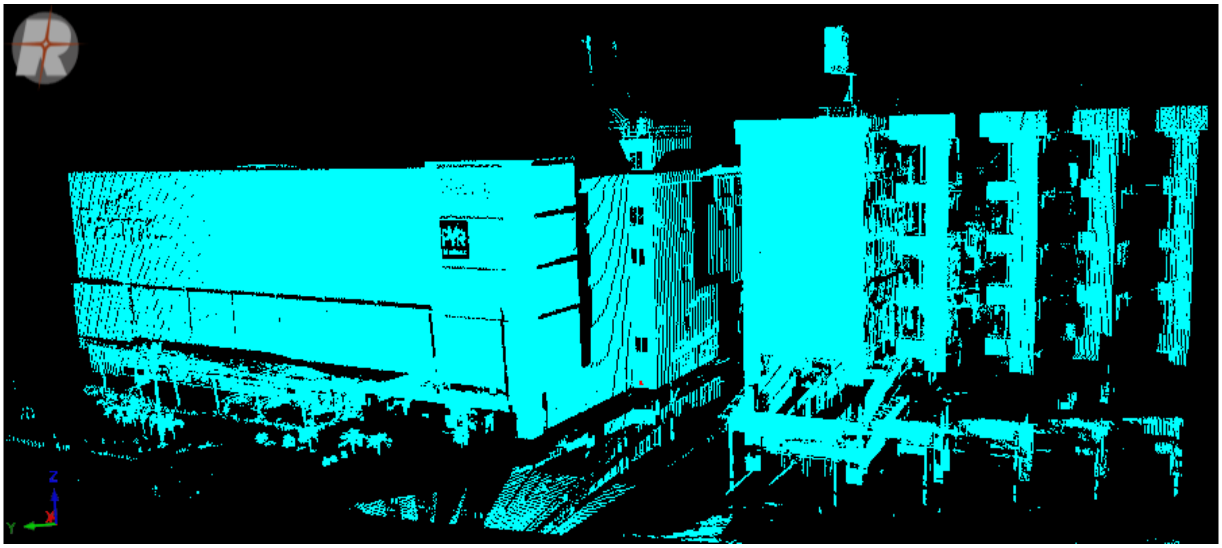

Figure 3.2 Laser Scan of the buildings in study area

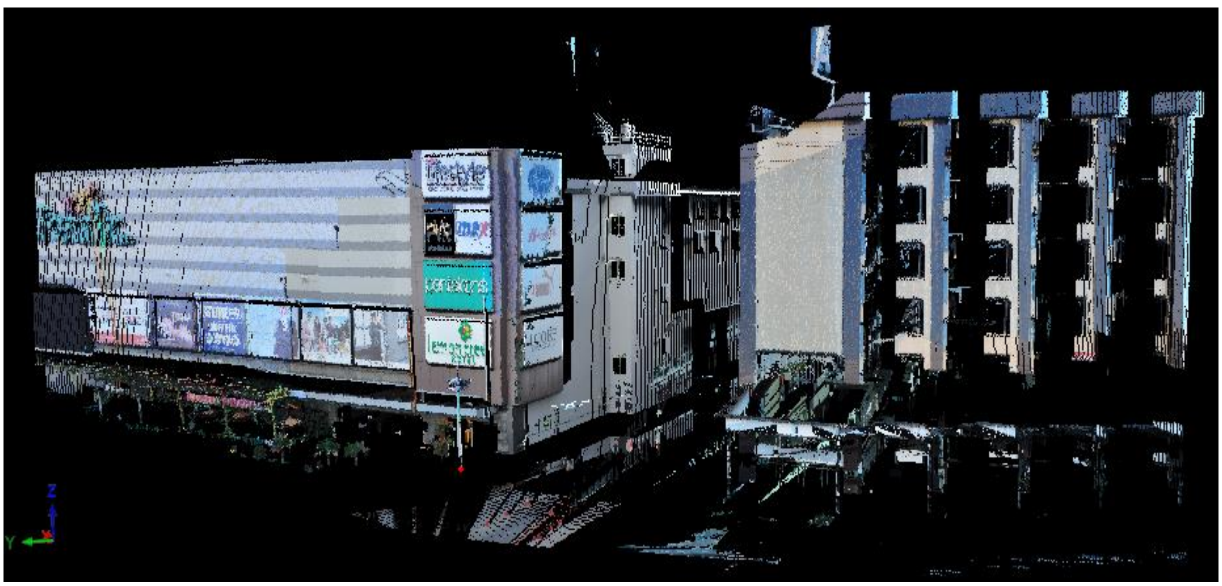

Figure 3.3 Added colored information to laser scan data

3.4.2 Pre-Processing

Preprocessing involves registration, multi-station adjustment, resampling, and segmentation etc. of the collected point cloud data and there are many ways these steps can be performed. The steps and preprocessing algorithms are selected purely based on the need. There are variety of semiautomatic and automatic methods proposed for 3D to 3D registration.(Kordelas et al., 2010) To do so several methods first extract geometric features from the scan to allow feature matching and alignment. Each scan is processed to extract 3D features like set of 3D lines, major 3D planes etc. One of these scans is selected as a pivot scan and is used for automated 3D to 3D registration by matching and alignment of the extracted geometric features.(Stamos et al., 2008) As a result all the scans are registered in the same coordinate system.

A common method of 3D to 3D registration involves collection of tie points during the data collection. Tie points are the common points that are used to match the features and their location along with orientation for 3D to 3D registration among multiple scans.

In the presented scenario, the registration of the multiple scans of the scene was performed using the tie points collected on the field and also some additional tie points were added for better result by manual identification of common urban features as tie points. The tie points were matched in each scan and merged together by automated 3D to 3D registration method. The result of merging of the two scans of the scene is visualized in fig. 3.4 below. The holes or the blank spots left by first scan are filled by the second scan of the scene.

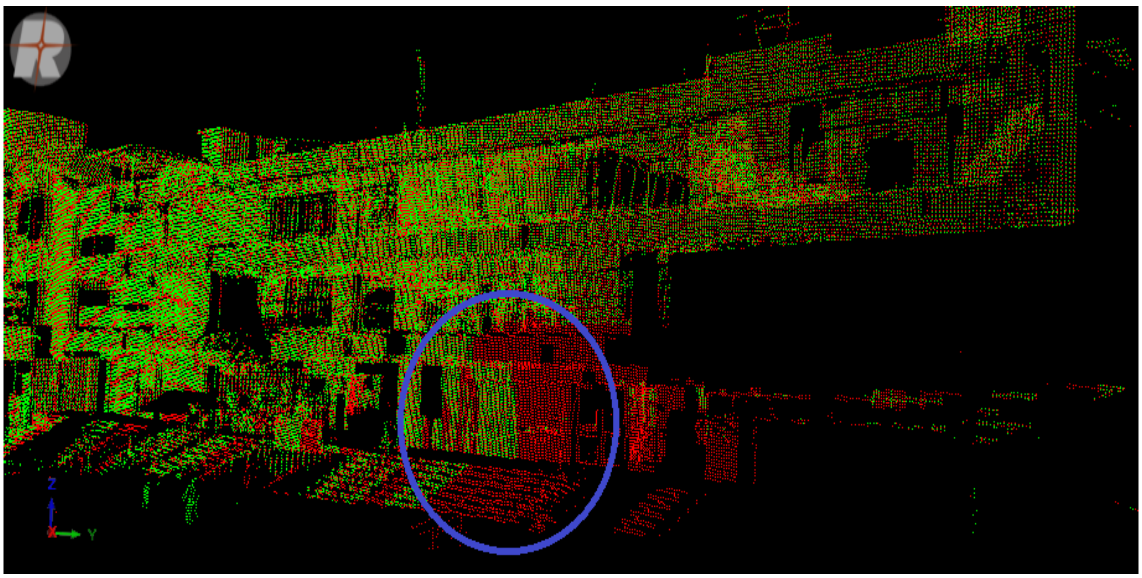

Figure 3.4 Merging of two scans of the scene

3.4.3 3D Semantic Model Reconstruction

The traffic noise level varies logarithmically as we go away from the road. With the assumption that the approximate modeling of the geometric attributes with error less than one meter would suffice the requirement of traffic noise mapping. So the processed point cloud data was utilized to estimate the geometric attributes of the buildings using the distance calculation tool in the operating and processing software that is RiSCAN PRO v1.7.9.

3.4.3.1 LoD0 Methodology

LoD0 is the 2.5 D model of the study area in which the footprints of the features are digitized on a 3D terrain. Google Sketchup is capable of retrieving terrain information from Google earth creating the terrain of the current view. The footprints of the buildings were digitized on this terrain to create 2.5D model of the study area.

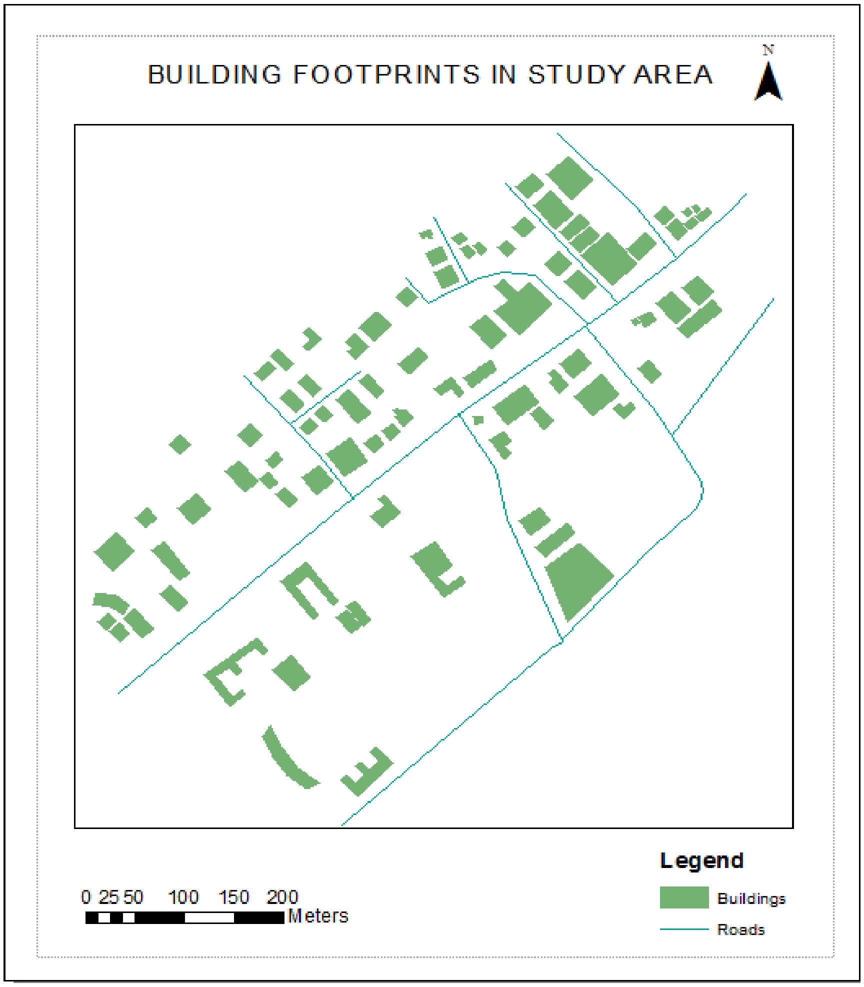

Figure 3.5 Vector 2D Map Of The Study Area

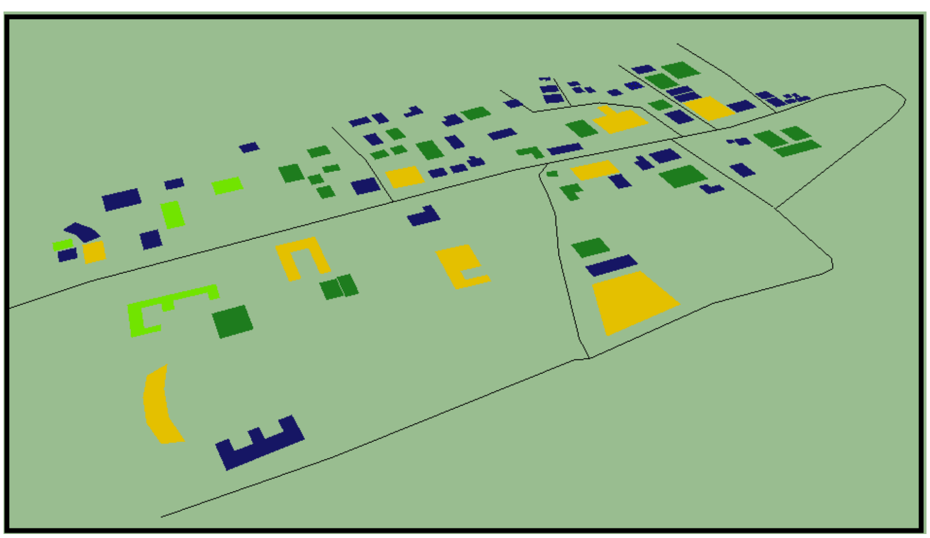

Figure 3.6 LoD0 Model of the study area

3.4.3.2 LoD1 Model Reconstruction

The required parameters to create LoD1 Model are LoD0 (Building footprint in previous step) and height of the buildings. As the LoD0 Model was read the height of the buildings were estimated after the point cloud data processing. To estimate the Height the distance measurement tool in RiScan Pro v1.7.9 was utilized

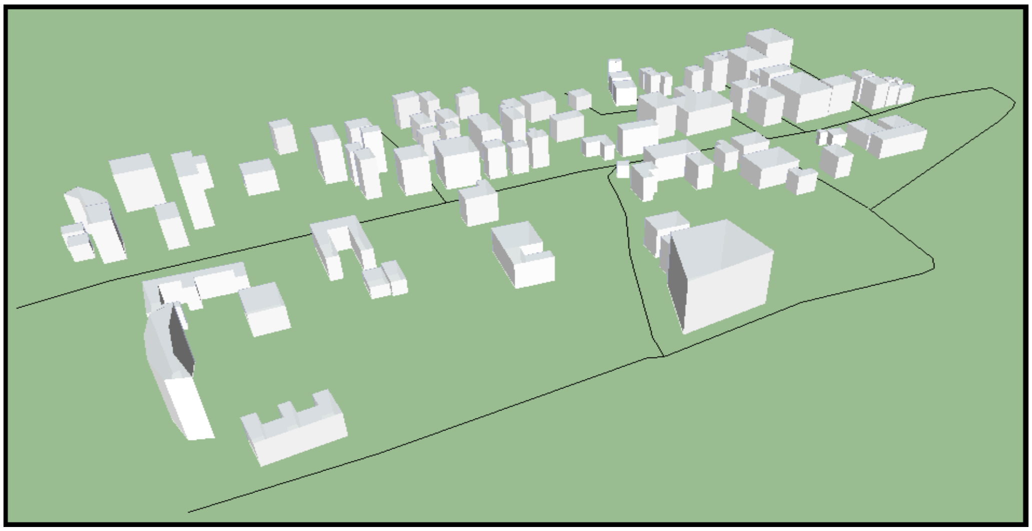

Figure 3.7 LoD1 Block Model of the Study Area

3.4.3.3 LoD2 Model Reconstruction

To generate the LoD2 model of the study area Sketchup plugin for CityGML was used. The different faces of the buildings were assigned a semantic information like wallsurface, roofsurface or groundsurface. Finally a LoD2 Model was ready for visualization and analysis.

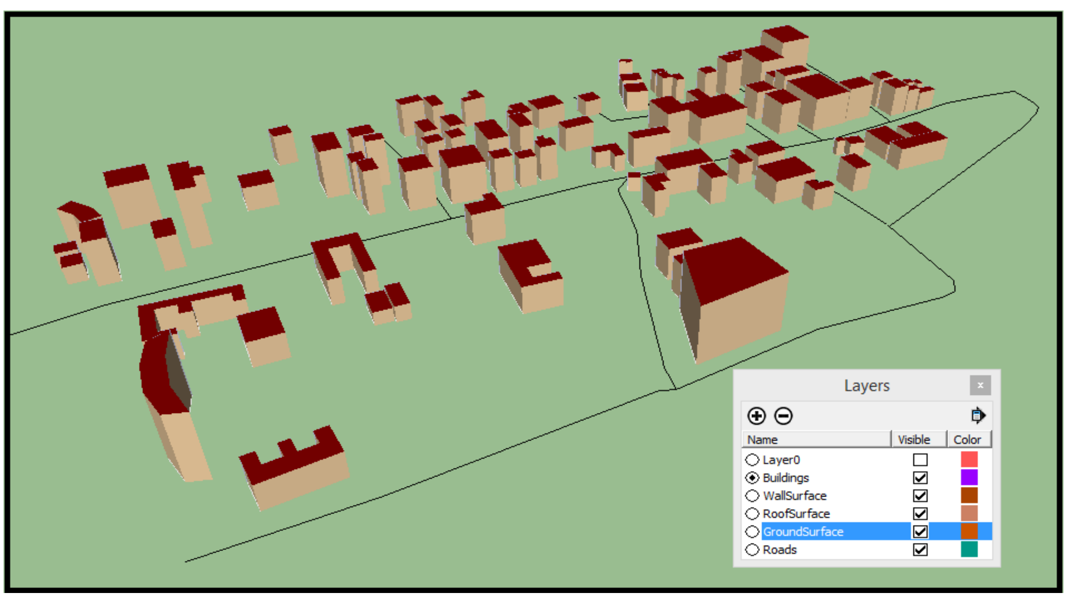

Figure 3.8 LoD2 Model of the Study Area

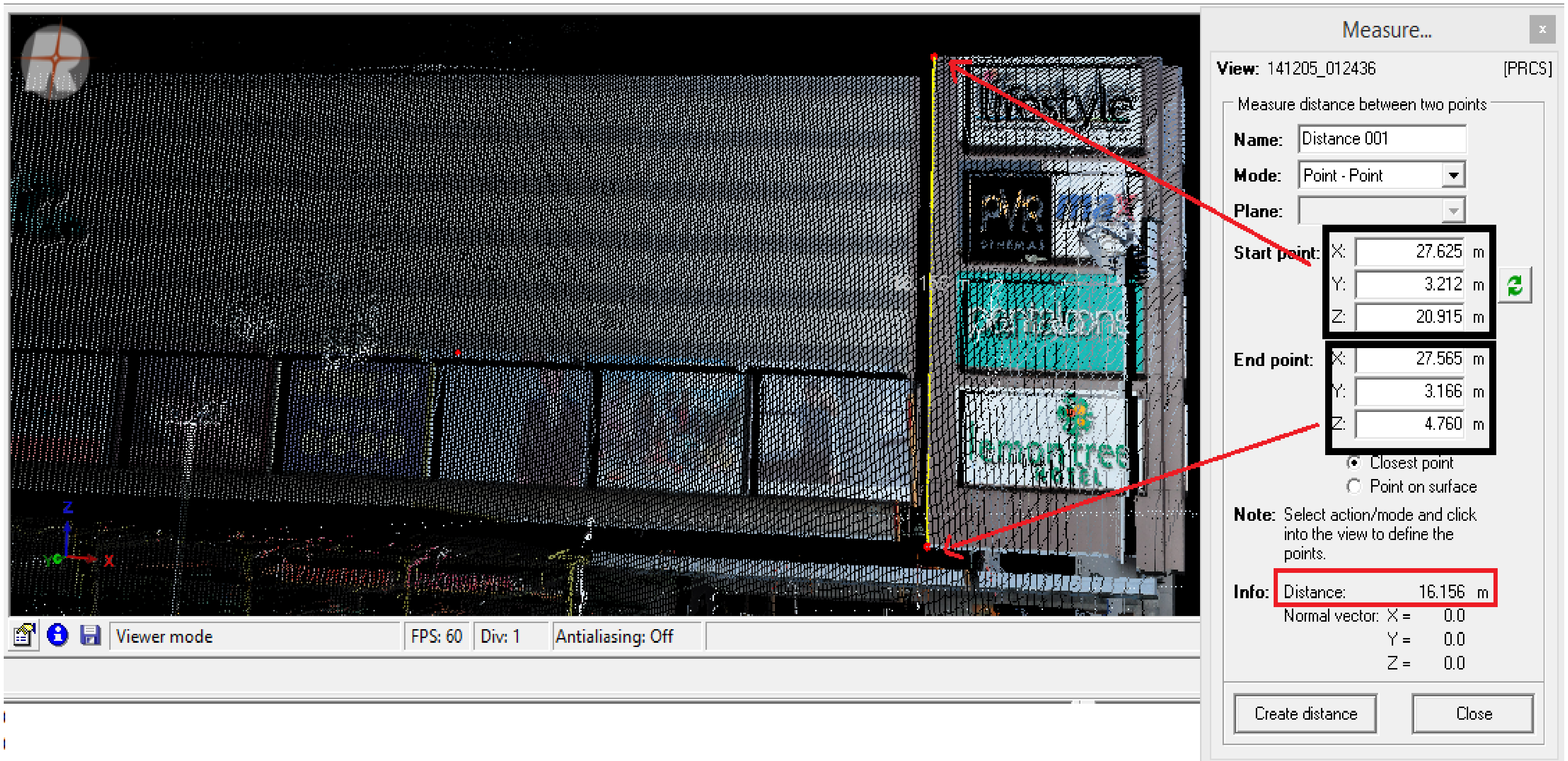

Figure 3.9 Geometric Attributes calculation using RiScan Pro

CHAPTER 4

TRAFFIC NOISE MODELING

4.1 Introduction to Traffic Noise Modeling

Noise pollution is one of the major problems raised by urban development and traffic noise is the most significant contributor to the noise pollution so, the evaluation of traffic noise impact is very important. Continuous exposure to heavy traffic noise above the threshold level introduces several negative effects on human health and quality of life. Traffic noise can be classified among the worst factors in terms of damage to people's health and wellbeing(Shigeru, 2012). Therefore, to reduce the noise pollution, it is essential to impose traffic regulations. Many countries have already introduced their own rules and regulations or follow the international standards (Pamanikabud and Tansatcha, 2010) to reduce traffic noise and also to impose vehicular noise emission limits. Some of the important terms in traffic noise modeling are defined below after a careful literature review,

Noise levels: The noise, resulting from the natural and mechanical sources and human activity, considered to be usually present in a particular area.

L_{50}: The sound level that exceeds 50 percentile of the time for the period under consideration.

L_{10}: The sound level that exceeds 10 percentile of the time for the period under consideration.

L_{eq}: It is the equivalent steady-state sound level in a given period of time such that it contains the same acoustic energy as the time-varying sound level during the same time period.

There are two ways to evaluate the traffic noise impact either by a measurement campaign or by a software simulation (WSEAS International Conference on Applied and Theoretical Mechanics et al., 2009). The measurement campaign is the direct way of noise level measurement to estimate the impact of noise. The road traffic noise source is determined by combining the noise emission of each individual vehicle forming the traffic flow(Kephalopoulos et al., 2011). The traffic noise simulation models mainly need traffic quantity for different vehicle types as per the standards followed, distance between carriage way and the receivers and the road surface attributes as input. The simulation of traffic noise is required primarily in below two cases,(WSEAS International Conference on Applied and Theoretical Mechanics et al., 2009)

1) To reduce number of measurement campaigns required to map the noise impact.
2) To evaluate the acoustical impact on infrastructure during design phase before construction and eventually avoid the post construction mitigation cost.

The traffic model is the acoustical description of a traffic flow, based on the directional source sound power levels of single moving equivalent vehicles.(Kephalopoulos et al., 2011). A brief review and description of some of the important traffic noise models is presented in subsequent chapter.

4.2 Review of Traffic Noise Prediction Models

Several models have been developed for different countries all over the world and this heterogeneity lies due to the variation of traffic conditions and other modeling parameters like type of vehicles in the country, types of roads and also meteorological conditions etc. These models aim towards simulation and prediction of traffic noise levels to facilitate the plan and designing of road and surrounding infrastructure or to estimate the behavior or impact for different traffic conditions. Due to heterogeneity in traffic conditions and other parameters many kinds of models have been proposed. (Suksaard et al., 1999) considered only two classes of vehicles to model the traffic noise impact. (Lam and Tam, 1998) proposed a noise prediction model based on Monte-Carlo approach. Later various studies were proposed that used GIS for analyzing traffic noise and development of traffic noise prediction models (Li et al., 2002; Pamanikabud and Tansatcha, 2003). A statistical model was proposed by (Calixto et al., 2003) to estimate road traffic noise in an urban setting(Shigeru, 2012). Some of the standard models that should be addressed include Dutch noise calculation methods Italian C.N.R. model, TNM by FHWA in the US, A French model that is NMPB, CoRTN and PRTN developed by the Department of Environment in the United Kingdom, RLS-90 by the Germany etc (WSEAS International Conference on Applied and Theoretical Mechanics et al., 2009).

Recently the traffic noise modeling trend is moving towards 3D modeling approach as the noise propagates in all directions so its simulation in 3D is essential to provide a realistic view of the conditions and analysis of complete scenarios that can arise in reality. Some of these studies include a motorway traffic noise model based on local traffic conditions in Tehran by (Reza Ranjbar et al., 2012). In this study noise impact on the building and ground surfaces are shown 3D format. (Pamanikabud and Tansatcha, 2010) demonstrates 3D analysis to investigate the traffic noise impact on building and surrounding area of a motorway. (Schrenk et al., 2008) demonstrate 3D visualization of a noise map within an urban street canyon.

4.3 Virtual Sound Level Meter (v0.41)

The virtual Sound Level Meter (VLSM v0.41) is a program initially developed using Python but later rewritten using MATLAB V7.10.0.499 (R2010a) with an addition of Signal Processing Toolbox V6.13 (R2010a). It is a free software to process and analysis audio data mainly used by students, educators, researchers and consultants as a tool for acoustic analysis of calibrated sound level recordings.(de Bruin et al., 2009) The first step of utilizing this tool is to set a calibration constant for the analysis. The calibration constant converts the .wav file inputs to pascals for analysis by VSLM.

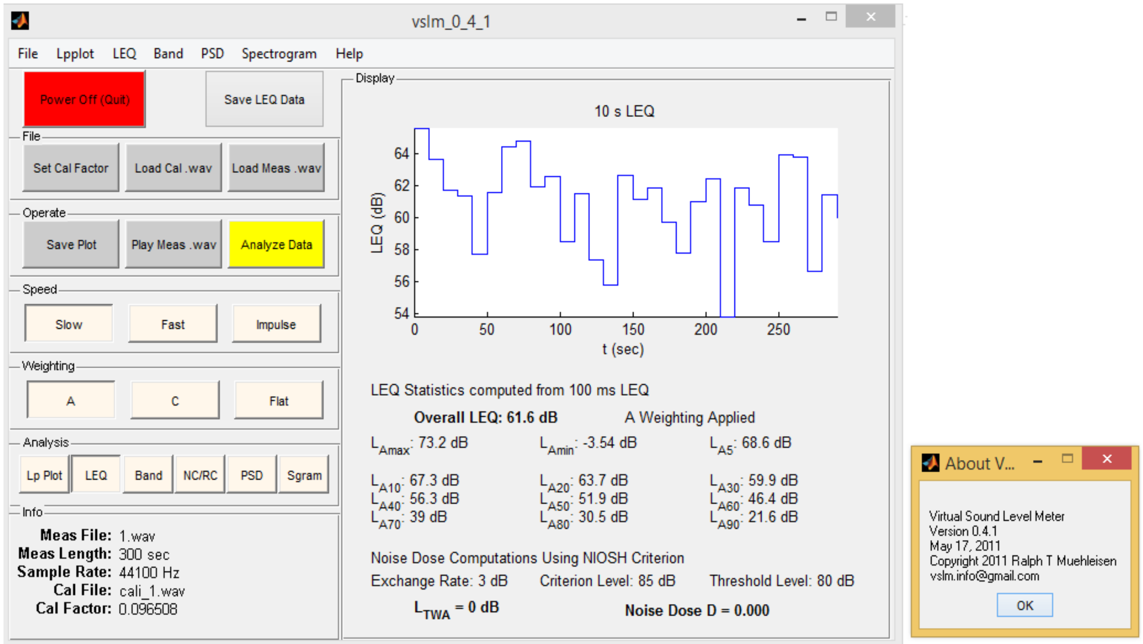

Figure 4.1 VLSM 0.41

The VLSM can be used to process the audio recordings three types of settings that are SLOW, FAST and Impulse. The 'impulse' is used to accurately capture the peak sound levels of impulsive noises such as gun shots or pounding equipment etc. and 'fast' time response is usually set when a source has a high dynamic range and fairly quick variations is present in the temporal response. The 'Slow' setting provides small amount of time averaging with a time constant of τ =1.0 seconds. The slow meter setting is the most commonly used setting on most standard sound level meters. The small amount of time averaging allows one to better estimate the average sound level in sounds with a limited dynamic range (de Bruin et al., 2009). VLSM has three modes in which analysis can be done,

Time domain: There are two time domain modes, in Lp mode software mimics a simple sound level meter and another LEQ mode, in this mode the software mimics an advanced sound level meter that can compute equivalent sound levels (LEQ) for the selected integration time.

Frequency domain: There are two frequency domain modes. These are Band mode and PSD mode. In Band mode the overall LEQ is computed in either the standard octave or 1/3 octave bands as per the user's selection of criteria and in PSD mode the overall power spectral density is computed.

Mixed domain: The mixed domain mode is the Spectrogram mode. In this mode the time varying power spectral density is computed and visualized in 2D or 3D.

4.4 Calixto Model

The assumption of Calixto model are,(Calixto et al., 2003)

1. The vehicle flow is the sum of the light vehicle and heavy vehicle flow that passes at a road during a certain time interval.
2. A heavy vehicle generates a stronger noise than a light vehicle.

The Calixto model is a simple statistical model that takes only the total quantity and the percentage of heavy vehicles into account to determine the traffic noise level. A generalized equation of Calixto model includes an equivalent traffic flow (Q_{eq}) as an independent variable to find the traffic noise level that is a dependent variable. The equivalent traffic flow is computed as,(Calixto et al., 2003)

$$Q_{eq} = Q^*(1 + n\times VP/100)$$

Equation 4-1

Where, Q is Total Quantity of vehicles n is Multiplication factor to find equivalent traffic flow such that accommodates for additional impact of heavy vehicles on overall noise and VP is the percentage of heavy vehicles

The statistical model by Calixto to find the equivalent noise level (L_{eq}) is a linear regression model with Log(Q_{eq}) as independent variable and L_{eq}(A) as a dependent variable as below,(Calixto et al., 2003)

$$L_{eq}(A) = a^*10^*\mathrm{Log}(Qeq)+k$$

Equation 4-2

Where, a, k are regression coefficients and L_{eq}(A) is the equivalent noise level.

4.5 Proposed Model

4.5.1 Modeling approach

Important three conditions to develop proper mathematical models that are capable of predicting the equivalent and statistical noise levels in a satisfactory manner are (Calixto et al., 2003),

- The model should be simple to be used by urban planners;
- The model should require only easily obtained data for the noise level calculation;
- The mode should incorporate satisfactory results as per the requirement.

4.5.1.1 Simple Calculation Method 1

The noise computation methods are designed such that traffic noise levels are accurately estimated and these are application for any area for noise simulation. The standard noise calculation methods in the Netherlands are based on extensive measurements done in the year 1970s and 1980s(Schrenk et al., 2008). These methods are categorized in various groups as per the purpose of the application. In cases where simple scenarios are considered with fewer calculations(Reza Ranjbar et al., 2012).

Standard Calculation Method 1 (SCM1) is generally used for initial assessment of noise impact as the reflections and obstruction of sound between the buildings is not considered in this method. It can be easily implemented for any condition and can have quick result for assessment.

Standard Calculation Method 2 (SCM2) is a more complex methodology which considers all the factors affecting noise levels. The factors considered also includes reflection and obstruction of sound between buildings which is not considered in SCM-1. The equation used for SCM1 is: (Schrenk et al., 2008)

$$SCM1 = E + Cs + Cj + Cr - De - Dd$$

Equation 4-3

Where, E is the emission level at source estimated using the traffic flow quantity and other traffic attributes, Cs is the noise correction term applied for the type of road surface, Cj is the correction term applied for any traffic-light controlled junctions, Cr is the correction term applied for any redound from vertical surface like buildings and noise barriers, Dd is the correction factor applied due to the distance attenuation from the source and De is the correction factor applied due to air attenuation, soil attenuation and meteorological influences.

4.5.1.2 Proposed Modified version of Calixto Model

Traffic Noise Modeling was aimed to be robust to calculate the traffic noise emitted by the source measured at the source having a traffic flow of fixed range of velocity. In Indian Scenario, consideration of various vehicles types is essential to create an effective Traffic Noise Model. As an account of this condition, a modified version of Calixto Model has been proposed here as below,

$$Leq(A) = a*10*Log(Qeq)+k$$

Equation 4-4

$$Qeq = Q(1 + \Sigma(ni \times Vpi)/100)$$

Equation 4-5

Where, Q is Total Quantity of vehicles, ni is multiplication factor to find equivalent traffic flow such that it accommodates for additional impact of heavy vehicles on overall noise. Qeq is the equivalent total quantity of vehicles, a and k are constant coefficients and Vpi is the percentage of vehicle type traffic.

4.5.2 Data Collection

The 30 samples were collected and each sample contained following attributes collected at the same time

- Total Traffic Flow (Q)
- Traffic Quantity of 2 wheeler vehicles (Qtw)
- Traffic Quantity of 3 Wheelers (Qthw)
- Traffic Quantity of 4 Wheelers (Qfw)
- Traffic Quantity of heavy vehicles (Qhw)
- Speed of each type of vehicles considered
- Noise Samples (Audio recording for noise level estimation)

The noise samples were collected at the center of the road. Average Speeds estimated were 36.6607, 33.211, 40.3855, and 32.7107 for two wheeler, three wheeler, four wheeler and heavy vehicles respectively. The audio recordings were processed using Virtual Sound Level Meter version 0.41 to estimate the equivalent noise level (Leq) for each sample point.

4.5.3 Audio Processing

Initially a Calibrator file with a calibrator RMSI input of 45 dB was loaded to calibrator the virtual sound level meter readings. All the analysis and calculation was performed with A weighting as the A-weighting filter covers the full audio range - 20 Hz to 20 kHz and the shape is similar to the response of the human ear at the lower levels (de Bruin et al., 2009). The Lp analysis mode is used to analyze the measurement file in a manner that mimics a standard non-integrating sound level meter. The VSLM software uses digital filters to simulate the time and frequency response of a non-integrating sound level meter that meets the ANSI S1.4-1983 standard. The sample Audio files were processed in time domain Lp mode to produce the simple audio signal as in fig 4.2. The L_{ASmax} value for one of the sample in this mode was obtained to be 69.7 dB at t=7.1 sec.

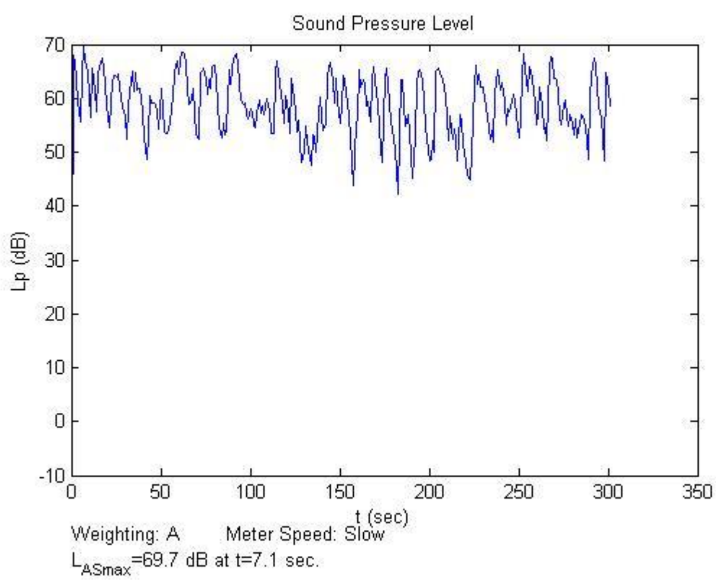

Figure 4.2 Audio Signal produced in time domain Lp mode

Audio samples were also processed in a band mode of frequency domain in which the averaging is done in frequency domain as shown in fig 4.3 and 4.4. The graph represents the variation of Lp that is peak noise in frequency domain. The peak noise in are averaged to represent a value for a band of frequencies. The maximum value for the same sound single in this domain was observer to be less than less than 60 DB.

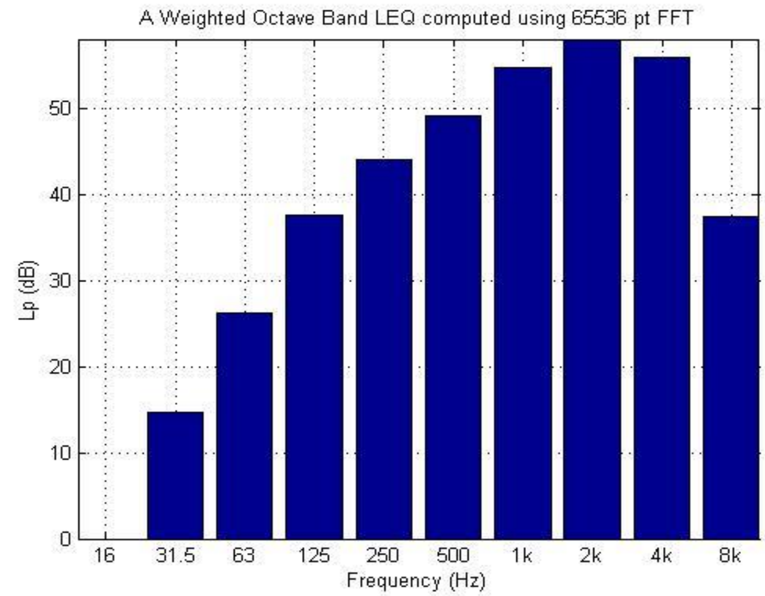

Figure 4.3 A Weighted Octave Band LEQ

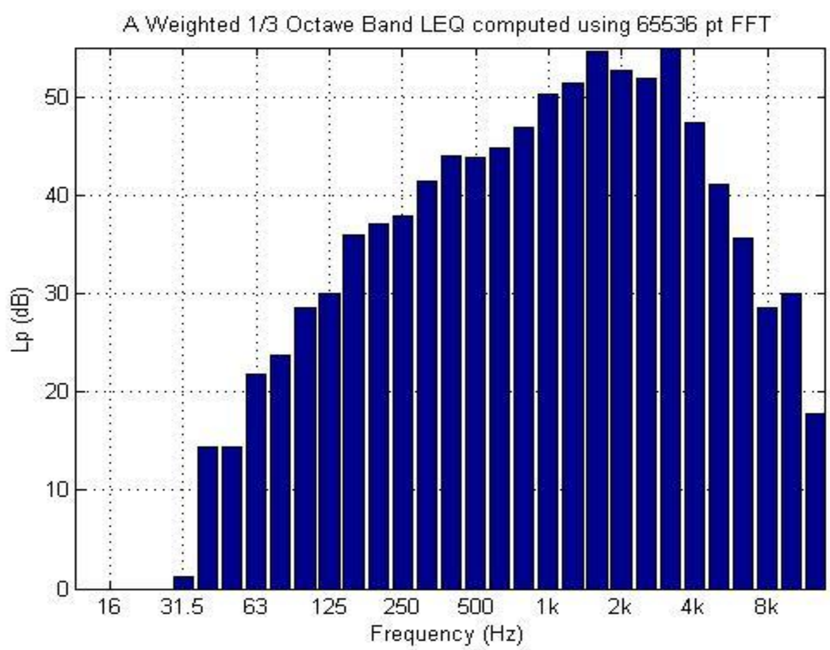

Figure 4.4 A Weighted 1/3Octave Band LEQ

Audio samples were also processed in a mixed mode (time and frequency) in which the averaging is done in both domains to produce the spectrogram as shown in fig 4.5. In this mode the maximum noise level was observed to be less than 40 dB.

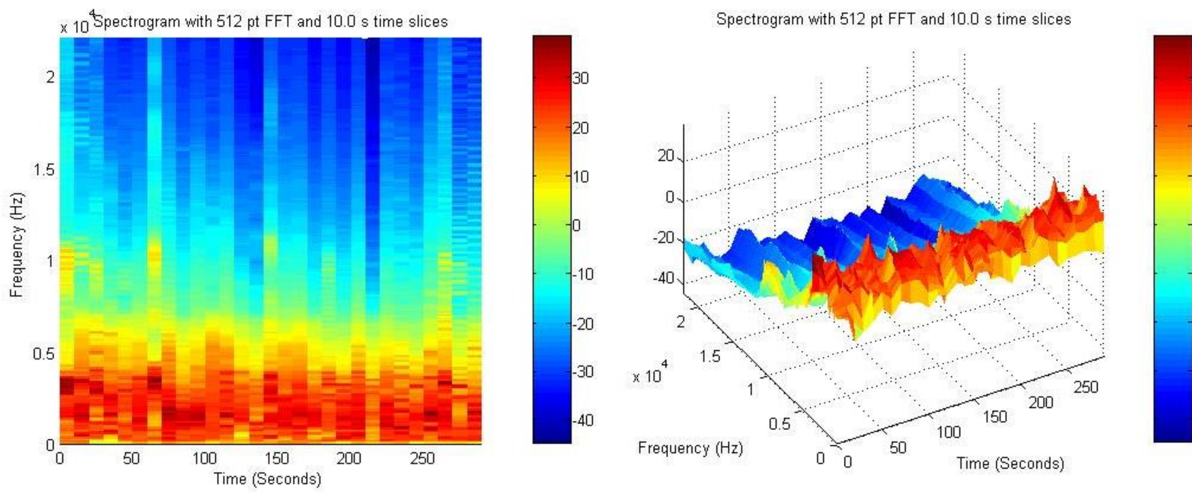

Figure 4.5 Spectrogram in 2D and 3D

Finally the audio single were processed in time domain Leq mode, which resulted in a digital signal. This mode is used by most of the advanced sound level meters and also for the further processing and analysis in the current study. The result of processing the same audio file are shown in fig 4.6 and 4.7.

The value for L_{Amax} was obtained to be the 61.6dB. The overall LEQ noise level observed in this mode was 61.6 dB which is greater than the noise level observed in both frequency domain and mixed domain averaging methods. The time domain averaging method considers the peak noise level in a selected frequency band for averaging in the time domain. So it was observed that selecting the integration time carefully in the time domain averaging method can depict the effect of continuous exposure of human ear to the traffic noise level above a threshold value in a given frequency range (A weighting).

LEQ Statistics computed from 100 ms LEQ

Overall LEQ: 61.6 dB A Weighting Applied

L_{Amax}: 73.2 dB	L_{Amin}: -3.54 dB	L_{A5}: 68.6 dB
L_{A10}: 67.3 dB	L_{A20}: 63.7 dB	L_{A30}: 59.9 dB
L_{A40}: 56.3 dB	L_{A50}: 51.9 dB	L_{A60}: 46.4 dB
L_{A70}: 39 dB	L_{A80}: 30.5 dB	L_{A90}: 21.6 dB

Noise Dose Computations Using NIOSH Criterion

Exchange Rate: 3 dB Criterion Level: 85 dB Threshold Level: 80 dB

L_{TWA} = 0 dB **Noise Dose D = 0.000**

Figure 4.6 Results of audio sample processing in LEQ Mode

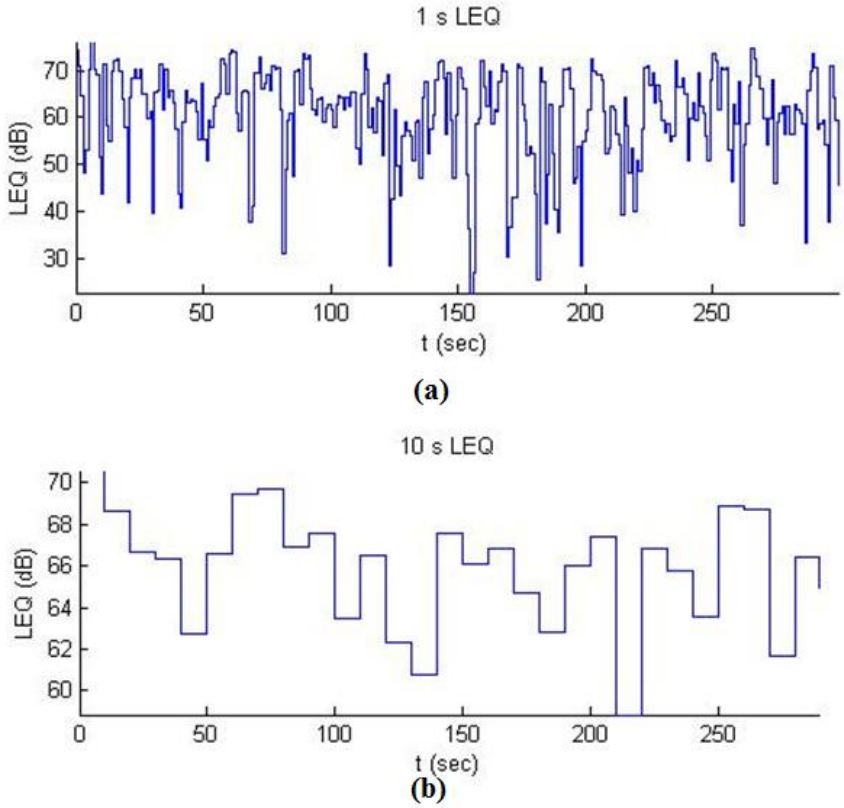

Figure 4.7 Time Domain LEQ graph with (a) 1 second integration time (b) 10 second integration time

All the 30 samples were processed to get the equivalent noise level Leq (A).

4.5.4 Equivalent Traffic Quantity

The goal was to estimate the multiplication factors for all the types of vehicles as per the proposed traffic noise model. The work by (Garg et al., 2014) estimated the value for the equivalence factors for each type of vehicle to calculate the equivalent traffic flow. The estimates for car, two-wheelers, medium commercial vehicles, three-wheelers, bus and trucks were measured by (Garg et al., 2014) to be 1, 1.13, 1.67, 2.36, 7.33 and 8.97 respectively. These values were used as a base to find the values of multiplication factors in a non-robust model. To make this model robust and fix the values of the multiplication factors a sensitivity analysis was performed and the values of multiplication factors were changed to fix the ultimate model with highest possible correlation between left and right side of the equation for proposed traffic noise model.

4.5.4.1 Sensitivity Analysis

Objective function coefficient sensitivity analysis(Hamby, 1995, 1994) was applied to estimate the values of multiplication factors. The steps developed to perform the sensitivity analysis were as below,

1. First the correlation values for each type of vehicle with calculated traffic noise level was calculated.
2. At start sensitivity analysis was performed for the variable with highest correlation value and then subsequently for other variables with descending order of correlation values.
3. To perform the sensitivity analysis the value of multiplication factor was first increased or decreased by 0.1 till the correlation between left and right side becomes highest possible.
4. The same process was repeated for each type variable and ultimately the model was fixed with highest possible correlation.

The values of multiplier coefficients estimated after sensitivity analysis are presented in table 4.1,

Table 4.1 Multiplier Coefficients estimated using 30 samples

Type of Vehicle	Multiplier Coefficient
Two Wheelers	3.1
Three Wheelers	0.7
Four Wheelers	1.1
Heavy Vehicles	6.1

The highest correlation value obtained through this procedure was 0.4664. So, to improve the results an attempt was made to find the outliers. A residual plot between left and right side of the traffic noise model equation is shown in the fig 4.8 (a). This plot was analyzed for the values that lie beyond 0.5 residual value and that matched with the sample points that were marked during data collection after being exposed to either temporary noise source or the temporary noise barriers. Seven points were identified as outliers as a result of analysis and removed.

The procedure of sensitivity was repeated for the remaining 23 samples to estimate the final values for multiplication factors as shown in table 4.2. The maximum correlation obtained was 0.8118234.

Table 4.2 Multiplier Coefficients for each type of vehicle

Type of Vehicle	Multiplier Coefficient
Two Wheelers	3.5
Three Wheelers	0.7
Four Wheelers	1.8
Heavy Vehicles	6.5

Using these multiplication factors the equivalent traffic quantity was calculated for all the 23 samples.

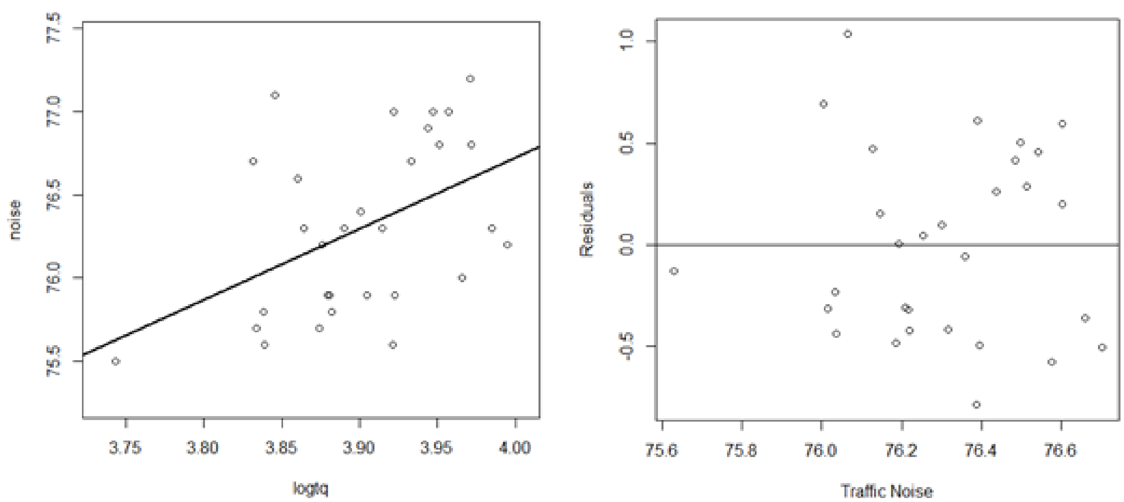

Figure 4.8 (a) Regression line before removing outliers (b) Residual Plot

4.5.5 Model Development

For modeling the traffic Noise with respect to equivalent traffic flow, out of 23 remaining samples, 15 were used and remaining 8 were used for accuracy assessment. The regression between log(Qeq) and noise level resulted in following model,

$$Laeq = 37.386 + 9.839 * \log(Q*(1+(3.5* P_{tw} +0.7* P_{thw} +1.8* P_{fw} +6.5* P_{hw})/Q))/\log(10)$$

Equation 4-6

Where, Laeq is the equivalent noise level, Q is the total quantity of vehicles, P_{tw} is the percentage of two wheeler vehicles, P_{thw} is the percentage of three wheeler vehicles, P_{fw} is the percentage of four wheeler vehicles and P_{hw} is the percentage of heavy vehicles.

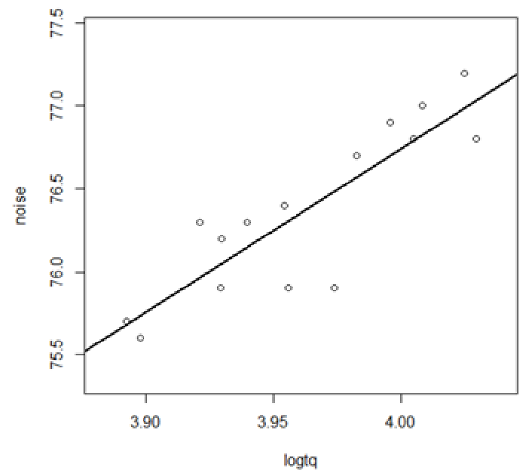

Figure 4.9 Model Regression Line and Corresponding Sample Points

4.5.6 Accuracy Assessment

The regression model developed was tested for accuracy using the remaining eight samples. To do so initially the values for noise level were predicted remaining 8 samples.

1. An average residual error between predicted and actual values was estimated to be 0.07700279 DB.
2. Correlation between actual value and predicted value was found to be 0.7187701
3. The root mean square error (RMSE) was estimated to be 0.364888 DB

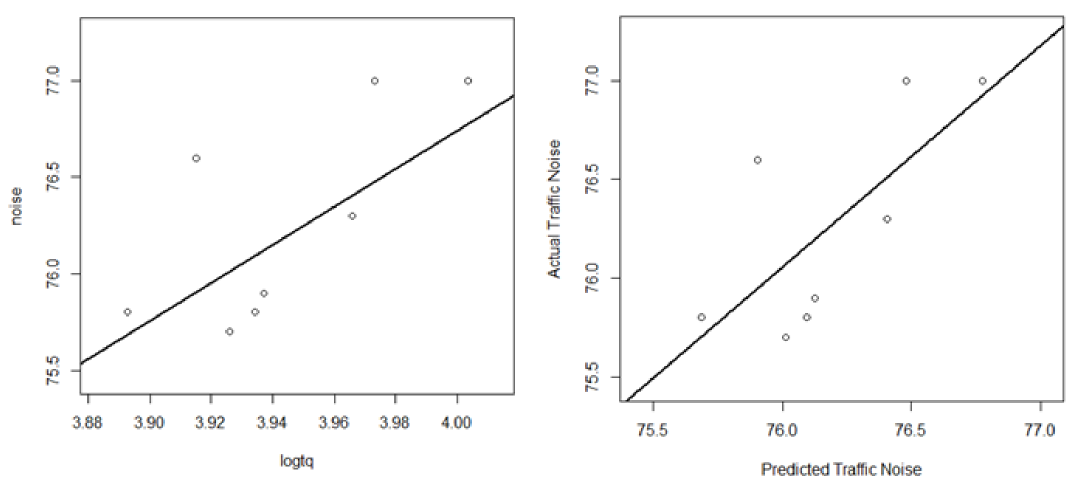

Figure 4.10 (a) Samples against the model regression line (b) Predicted Traffic Noise vs Actual Traffic Noise

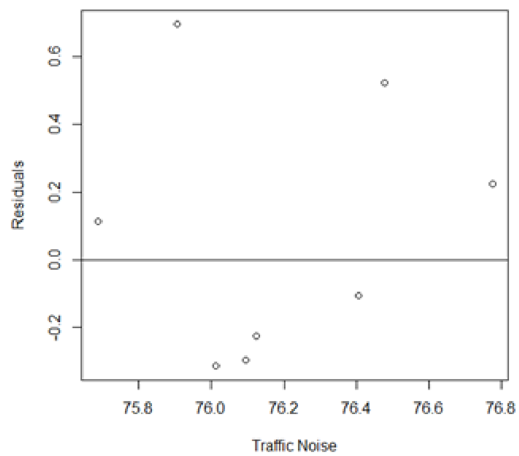

Figure 4.11 Residual Plot of 8 Samples

4.5.7 Other Traffic Noise Factors (SCM-1)

Correction term due to the type of road surface i.e. Cw for an asphalt road is 0 as the road gradients Lm and Bm for asphalt road are 0 (Reza Ranjbar et al., 2012) so, it was assumed that there is no reduction in overall noise due to road surface.

The correction factor due to the distance attenuation from the source (Dd) was estimated by applying the formula for noise attenuation as below,

$$Dd = 10*\log(D)$$

Equation 4-7

Where D is the 3D Euclidian distance of observation point from the road polyline that is the source of noise pollution.

CHAPTER 5

WEB BASED VISUALIZATION AND SPATIO-SEMANTIC ANALYSIS

5.1 Geographical Information System

The geographical feature, is made up of two components positional component that defines the object's position, shape and the topology represented by geometric primitives like points, lines, polygons and pixels and the descriptive component, expressed as non-spatial properties of the geometrical features by means of attributes like numbers, strings, date etc. Considering this definition of a geographical features, Geographical Information System (GIS) can be defined as a complex system that manages the geographical position of objects; their attributes; their spatial and attribute relationships; time factor of dynamic phenomena.(Gomarasca, 2009a). In GIS geographic features that are geospatial in nature, are stored as alpha-numerical data and image data, derived by satellite, airplane and/or ground acquisitions.(Gomarasca, 2009b).

The important functions of a GIS system are collection, structuring, manipulation, analysis, and presentation (Abdul-Rahman and Pilouk, 2008).

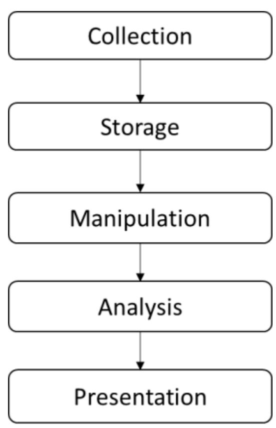

Figure 5.1 Function of GIS

Data Collection is one of the most important step of GIS. Data properties like spatial, spectral and temporal resolution of the imagery defines the application scope of the GIS. There are many tools and techniques that have been developed and evolved to generate the raster and vector data and features and their attributes. The methods of data collection can be devised into three categories Satellite based, Aerial, and Ground survey. The processing of this data can manual, semiautomatic or automatic in nature (Abdul-Rahman and Pilouk, 2008).

The next step of GIS is the storage of raster and vector data structures. Relational database systems have been evolved to support many spatial data types, queries and operation which are increasing day by day and it gave birth to a new term called as spatial database systems. (Güting, 1994) defines a spatial database system as a database system that offers Spatial Data Types in its data model and query language and supports spatial data types in its implementation, providing at least spatial indexing and efficient algorithms for spatial join.

Manipulation and analysis go hand in hand in a GIS system Manipulation is essential and is performed to support analysis and to derive spatial information from the available data. The Generalization and transformation are the minimal manipulation operations that a GIS must offer. Weibel and Jones, 1998 classified generalization into two main types, known as the cartographic and the conceptual generalization. Transformation is support for the re-projection and scaling of spatial features and maps (Abdul-Rahman and Pilouk, 2008). A spatial object can be represented with two models, i.e. geometric (i.e. simple feature specifications, SFS) and topological (i.e. complex feature specifications) ("Simple Feature Access-Part 2," 1999). While the geometric model provides direct access to the coordinates of individual objects, the topological model refers to the composing smaller elements (primitives) and encapsulates some of their spatial relationships. The metric operations like area, volume computations are performed on the geometric model and analysis based on neighborhood operations like buffering, zoning and overlay are performed on topological structures (Abdul-Rahman and Pilouk, 2008; Ruiz et al., 2002).

Spatial analysis is the essence of GIS. It interprets useful information from raw data through operations like transformations, manipulations, and methods that add value to geographic data, support planning and design decisions, reveal patterns and anomalies that are not immediately obvious (In Longley et al., 2005).

The presentation is the final stage where the maps, graphs and other results are visualized are visualized. The cartographic rules and standards have been defined for better representation of the geospatial data and attributes.(Raubal, 2008)

5.2 Web GIS

The basic principle of the World Wide Web (WWW) is to provide free access, sharing and allow globalization of the information. GIS is adapting more and more to the open source technologies making it publicly available. It has been recognized worldwide that WebGIS is the future of developments in geographical information systems (GIS) (Yan-tao and Jiang-guo, 2008). Through Web GIS it's becoming possible to access geospatial data and conduct geospatial analyses on the Internet. Using webGIS, recently, many based application are being developed such as semantic approach to visualize historical natural hazards by (Dong et al., 2013), public health information visualization platform by (Lu, 2005) etc. The number of digital archives including spatial databases are increasing continuously. Many has unique data for unique purposes so systems that can identify the data of interest and a standardized way to access such data is a complex and necessary requirement. To standardize these developments, transactions and transformations, systems for an innovative database organization like Spatial

Data Infrastructure (SDI) and format standardization like Open Geospatial Consortium (OGC) have been developed.

With latest advancements in 3D technologies like WegGL it has become possible to visualization 3D information on the web. With web based free and open source innovative solutions of 3D GIS like cesium globe, 3D WebGIS is becoming more popular.

5.2.1 Client-Server Architecture

Web GIS has been evolving and it can be modeled as three tier client server architecture. A client architecture can thin client architecture or thick client architecture.(Alesheikh et al., n.d.).

Thin Client Architecture: In a thin client architecture, the client can only provide interfaces to the user. The processing and analysis is handled on the server side. The advantages of thin client architecture are, there is centralized resource management at server, data can be easily manipulated and managed, and this is a cheaper approach. But this approach has some disadvantages like there is no local accountability, and is inefficient in cases like processing large data volume, this is a less interactive approach, vector data cannot be visualized on client side.

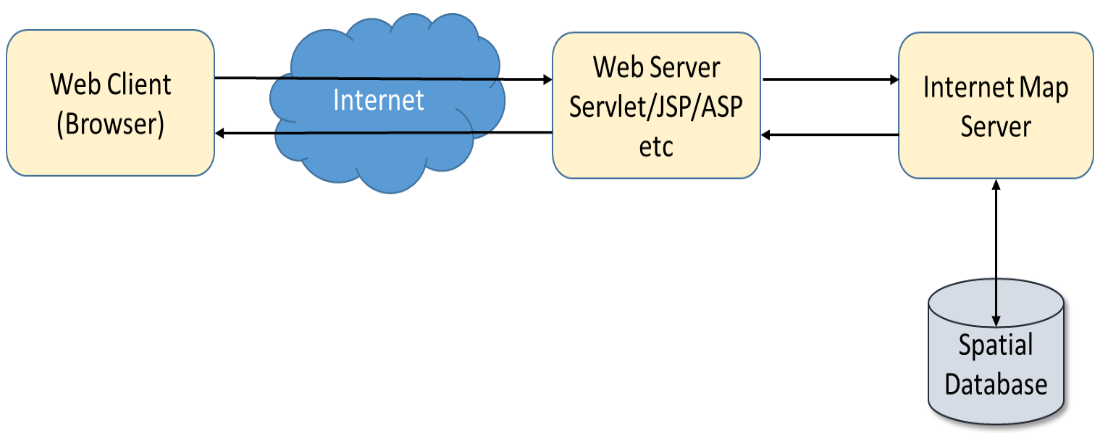

Figure 5.2 Thin client architecture

Thick Client Architecture: In a thick client architecture, the web browser is equipped extensions like plugins, Java Applet, Javascript Libraries, Active X etc. which give a browser dynamic behavior and adds the capability of client side processing in the architecture. This approach has advantages like in this approach vector data can be used, advanced interfaces can be developed like cesium globe for geospatial visualization etc. Disadvantages of this approach are Plugin is required for many extensions, sometimes browsers are not compatible to support the extension etc.

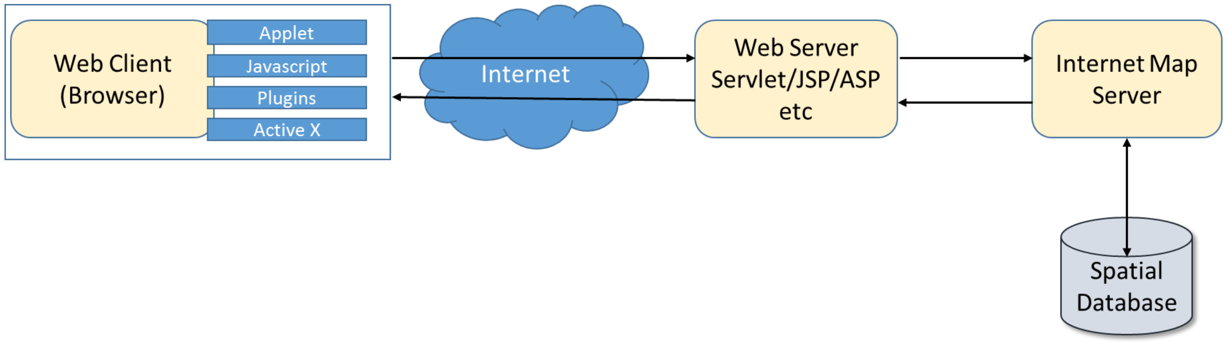

Figure 5.3 Thick Client Architecture

5.2.2 Jason Based Web GIS framework

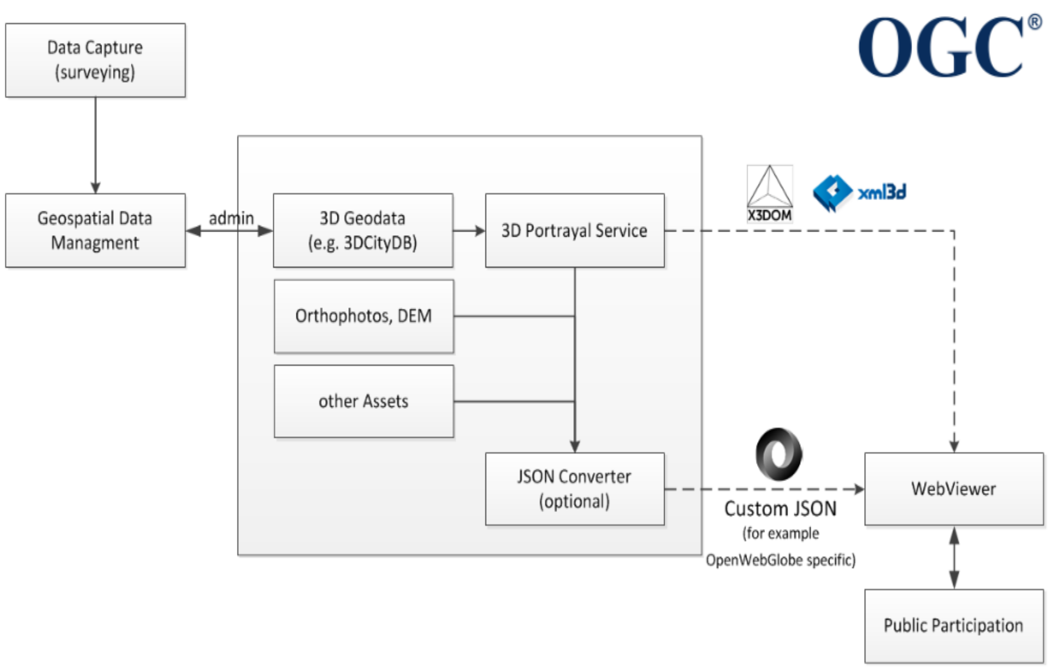

Figure 5.4 JSON Framework for Tile based rendering (Christen et al., 2013)

JavaScript Object Notation (Jason) based 3d rendering service implementation is one of widely adapted standards. In many cases X3D has been replaced with JSON. Just like SOAP API is associated with XML data Model, REST API is associated with a JSON data model that supports attribute based query. JSON supports the tile based approach of data rendering. Using softwares like 3DCityDB, tiles for CityGML can be generated and these tiles can be stored in the form of JSON (Christen et al., 2013).

JSON tiles provide following advantages over X3D,

1. Attribute based query is supported directly on the client side.

2. Progressive visualization: JSON Tiles allow only the required area to be visualized and fetched from the server.

The tiles for CityGML can be generated using 3DCityDB. Once generated, Json Converter can be used to create the JSON Objects. These are then sent to web browser for visualization.

5.3 Cesium

Cesium is a JavaScript library that provides functions for client-side virtual globe and map built using WebGL. Cesium is a four layered architecture such that each subsequent layer adds functionality, raises the level of abstraction, and depends on the layers underneath it (Analytics Graphics, Inc., 2011)

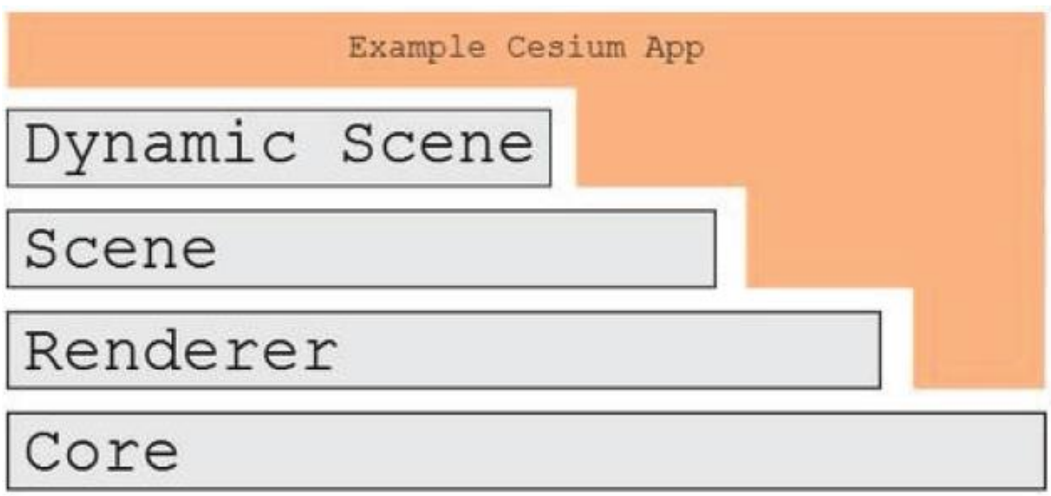

Figure 5.5 Cesium Layerd Architecture (Analytics Graphics, Inc., 2011)

Core: Core is the lowest level of abstraction. It contains basic low-level data types and functions that are used by all the applications. Some of the important types and functions are Matrices, Vectors, Transformations, Map projections, Geometric routines etc.

Renderer: Renderer is a higher level of thin abstraction over WebGL. The Renderer is used by the Scene to create WebGL resources for Cesium primitives such as the globe and 3D models. It is an easy to use API providing advantage to developers for fast and efficient programming.

Scene: Scene is higher level of abstraction built on top of Core and Renderer. It provide relativity high-level map and globe constructs such as 2D maps, 3D globe, 2.5D view

Dynamic Scene: Dynamic Scene is the highest level of abstraction provided in cesium library. It has been built on top of all the previous three layers. This layer enables data-driven visualization.

The cesium globe was deployed on node.js on local machine. The web globe retrieved using Google chrome is shown fig 5.6,

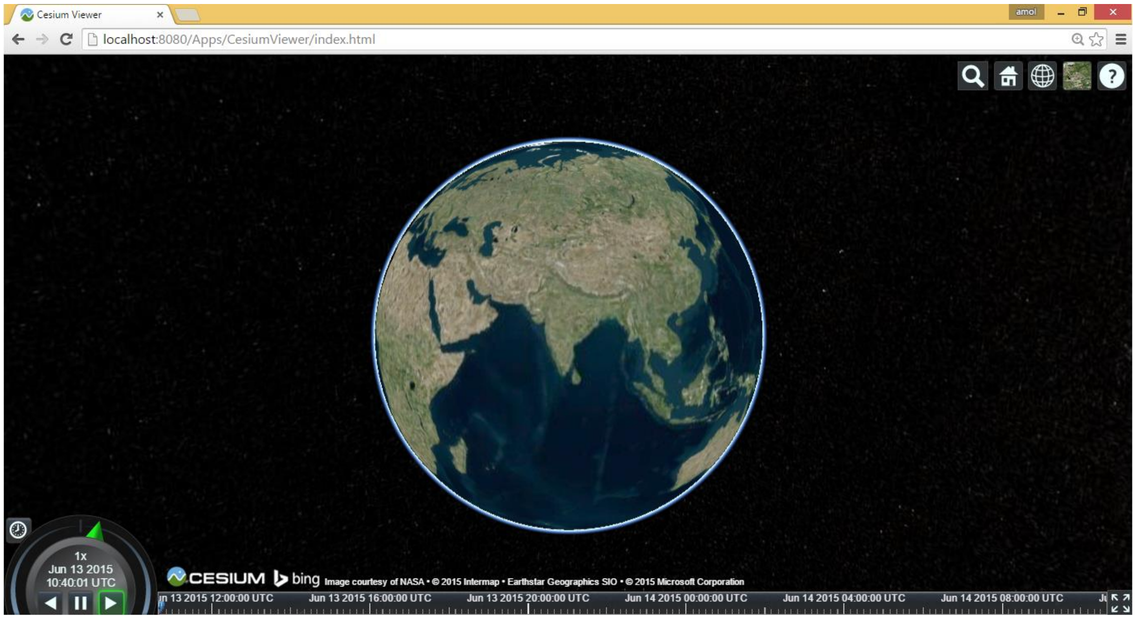

Figure 5.6 Cesium Web Globe retrived using Google Chrome

5.4 3DCityDB Spatial DBMS

3DCity Database abbreviated as 3DCityDB is distributed in two version, one version for Oracle Spatial and another for PostGIS. Here the PostGIS version is discussed and utilized as part of this work. 3DCity Database is a fully Open Source software which has the ability to store and analyze CityGML documents in PostGIS. It consists of a database schema to support CityGML data structure along with procedures used by importer/exporter tool that comes with the 3DCityDB package.

Key Features of the 3D City Database	Oracle	PgSQL
Semantically rich, hierarchically structured model	✓	✓
Five different Levels of Detail (LODs)	✓	✓
Appearance data in addition to flexible 3D geometries	✓	✓
Representation of generic and prototypical 3D objects	✓	✓
Free, also recursive aggregation of geo objects	✓	✓
Complex digital terrain models (DTMs)	✓	✓
Management of large aerial photographs	✓	✓
Version and history management	✓	X
Matching/merging of building features	✓	✓
Key Features of the Importer/Exporter		
Full support for CityGML 1.0 and 0.4.0	✓	✓
Exports of KML/COLLADA models	✓	✓
Generic KML information balloons	✓	✓
Reading/writing CityGML instance documents of arbitrary file size	✓	✓
Multithreaded programming facilitating high performance CityGML processing	✓	✓
Resolving of forward and backwards XLinks	✓	✓
XML validation of CityGML documents	✓	✓
User-defined Coordinate Reference Systems	✓	✓
Coordinate transformations for CityGML exports	✓	✓
Matching/merging of building features	✓	✓

✓= equivalent support, ✓= Oracle-specific support ✓= PostGIS-specific support X = not supported

Figure 5.7 Key Features of 3DCity Database Version 2.0.6 and Importer/Exporter (Giovannini et al., n.d.)

5.5 Proposed Web GIS Framework

A thick client web architecture has been developed to visualize the 3D Models on cesium globe for semantic analysis. Cesium supports drawing and layering of high-resolution imagery (maps) from several standard services (Analytics Graphics, Inc., 2011). On top of imagery layer it supports various 3D vector data formats like GeoJason, kml etc. for visualization and analysis. Fig 5.8 shows the complete implementation architecture of the developed Web GIS framework. The web service call was implemented using Jason objects embedded in a simple XmlHttpRequst protocol.

5.5.1 Web Server

The web server serves two purposes,

1. Interaction with Spatial database that is PostGIS (+ 3DCityDB)
2. Conversion of 3D features and other associated attributes to Jason Response Objects.

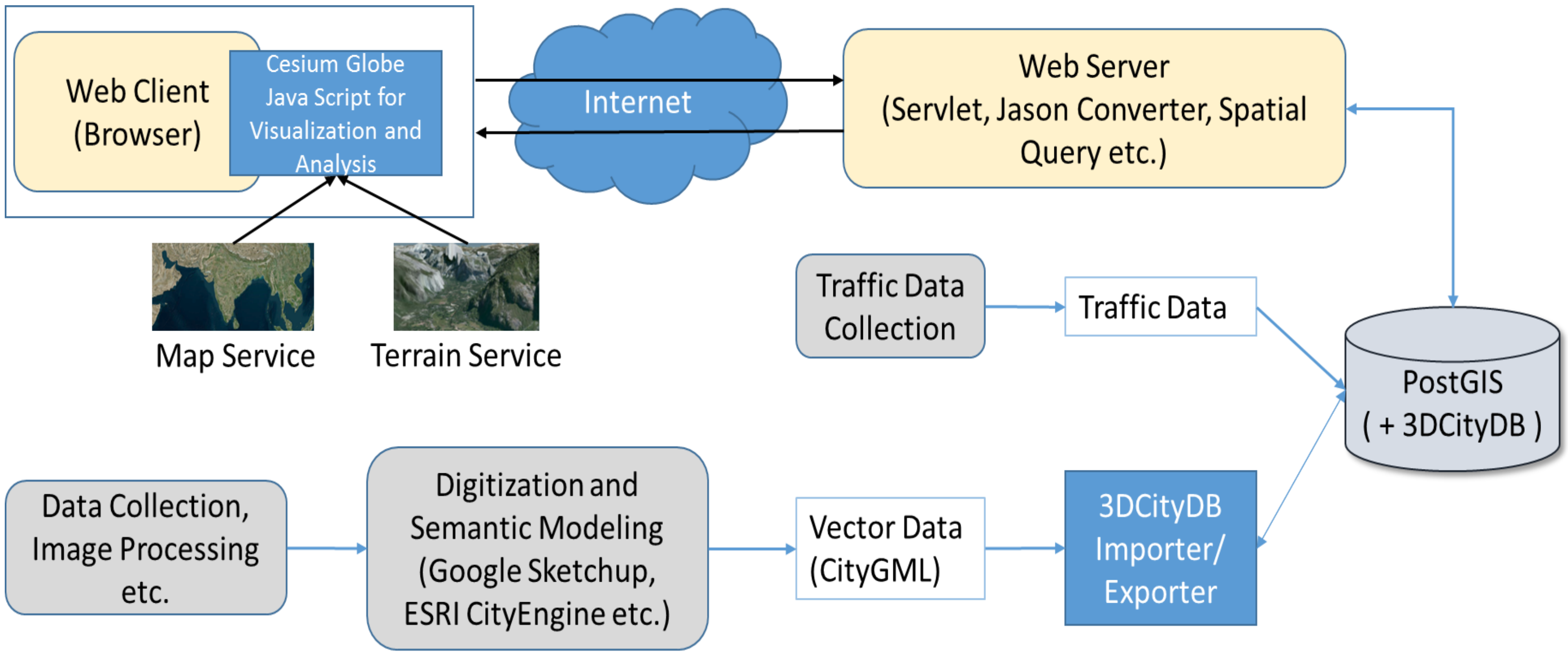

Figure 5.8 Proposed Architecture Traffic Noise Mapping and Visualization

The main focus of spatial data queries was the efficient retrieval of 3D building features from 3D City Database using the location of object as one of the conditional query attribute. Apart from the geometry of the object, the relative parameters like traffic noise level, building name and year construction of the building were retrieved from the database as per the request from the end.

The response expected on the front end is a Jason object so a converter is implemented to transform the data retrieved from database into Jason object. The Jason object were sent back to the web client for visualization and further analysis.

5.5.2 Cesium Web Client

The developed cesium web client supports visualization in two modes, Voxel based 3D visualization and Semantic 3D Visualization (LoD0, LoD1 and LoD2).

The important GIS functions implemented on web client for the analysis and visualization for 3D geospatial information on traffic noise are,

1. Voxel Model and Semantic Model Visualization
2. Voxel Based Spatio-Temporal 3D Traffic Noise Mapping
3. Spatio-Semantic Traffic Noise Mapping

5.5.3 Semantic Model and Voxel Model Visualization

A web service call to the web server to fetch the LoD1 and LoD2 buildings was implemented. The Jason objects for both LoD1 and LoD2 retrieved at the web client were visualized on the Cesium web globe as shown in fig 5.9 and 5.10 respectively,

To create 3D traffic Noise Maps, such that the vertical profile of the traffic noise level is mapped on the building walls, it is necessary to create 3D observation points at regular intervals over the area of interest. To perform this task, a voxel model was generated using the LoD1 block model of the study area and visualized on cesium globe as shown in fig 5.11.

Figure 5.9 LoD1 Model Visualized on Cesium Globe

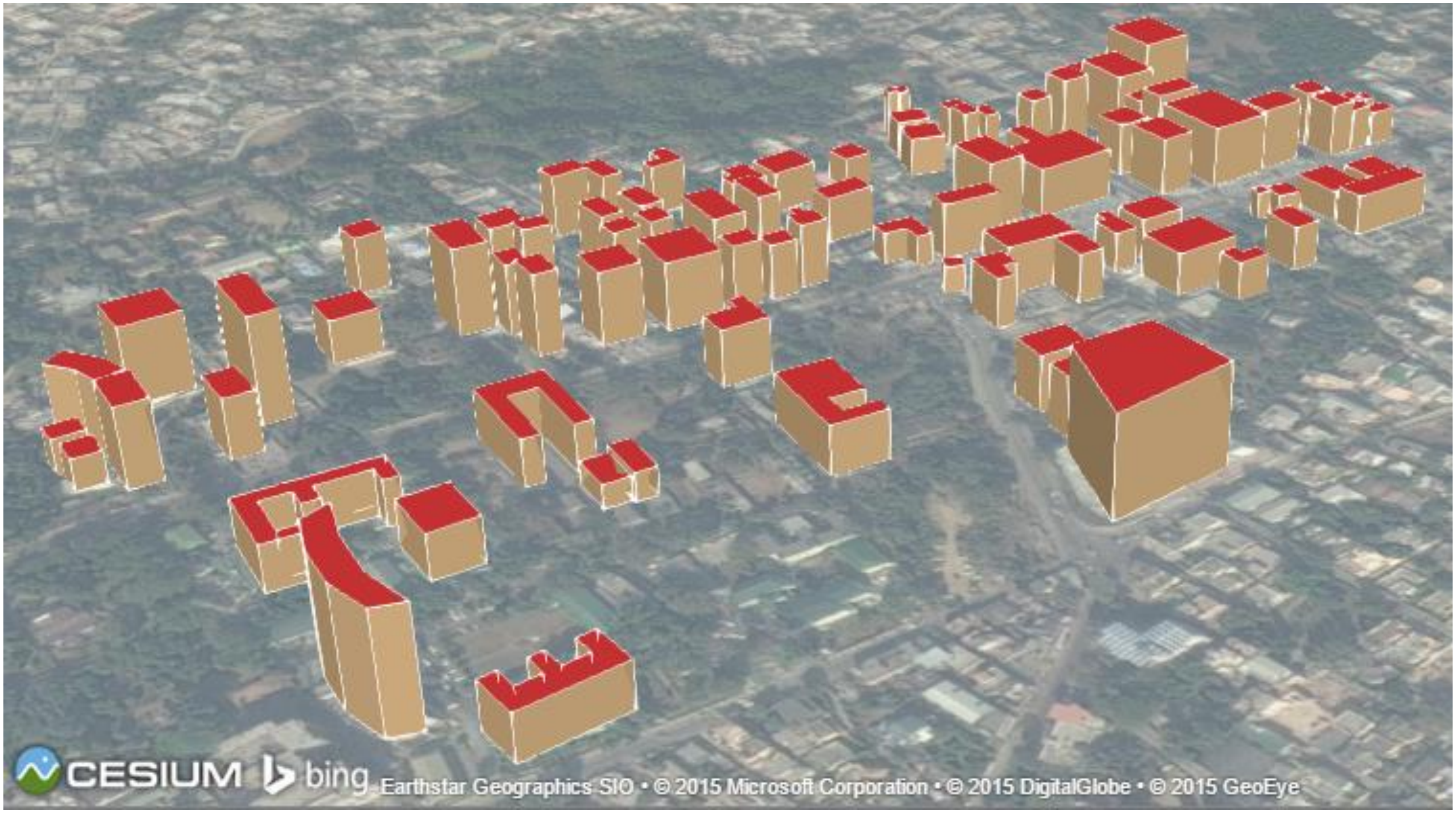

Figure 5.10 LoD2 Model Visualized on Cesium Globe

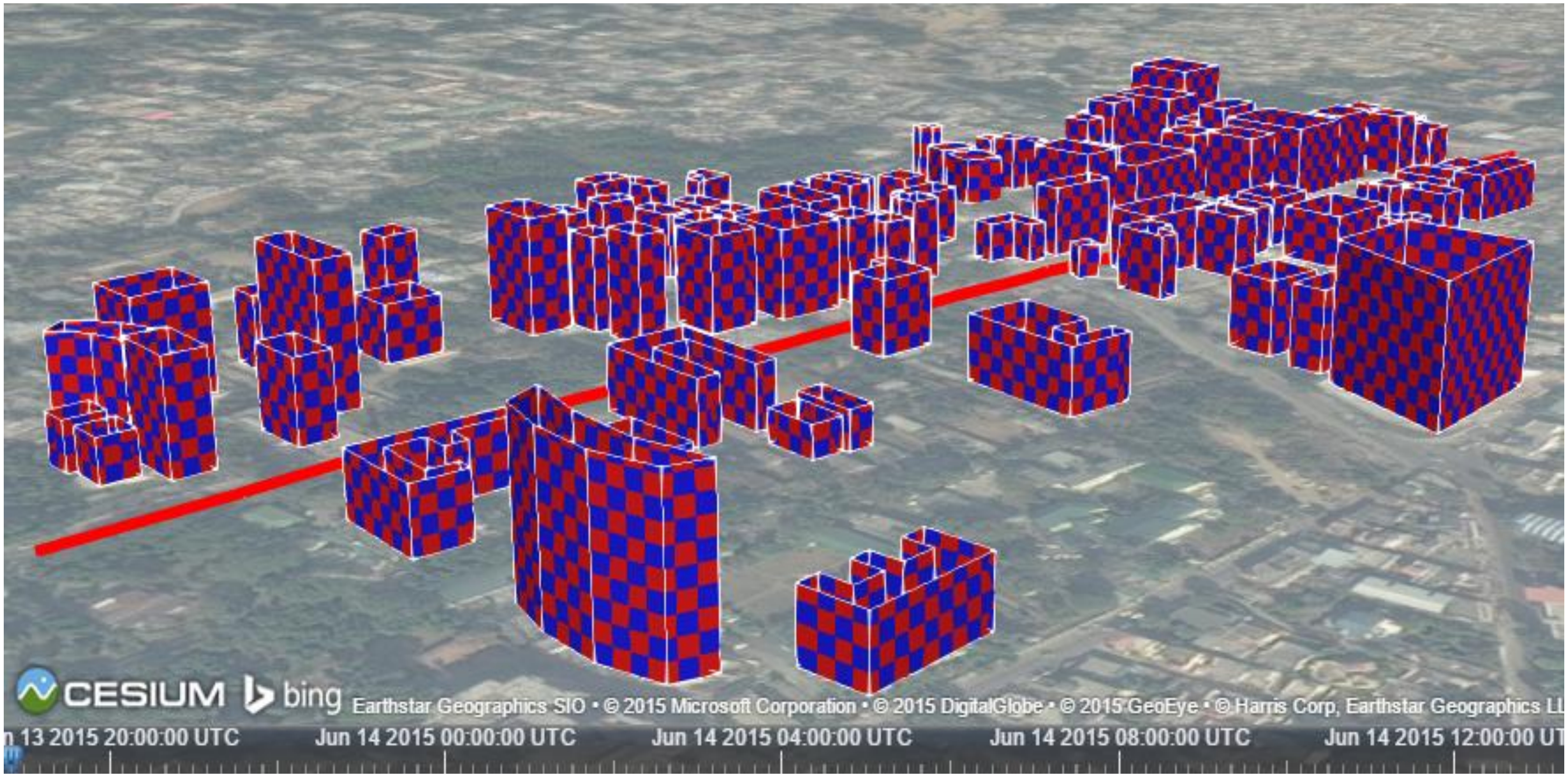

Figure 5.11 Voxel Model Visualized on Cesium Globe

5.5.4 Voxel Model Based Spatio-Temporal Traffic Noise Mapping

As per the Standard Calculation Method 1 (SCM1) method, the distance of the observation point is one of the important noise reduction factor. So an algorithm was developed to calculate the 3D distance of observation point from the road polyline. The flow diagram of the algorithm is shown in the fig. 5.12.

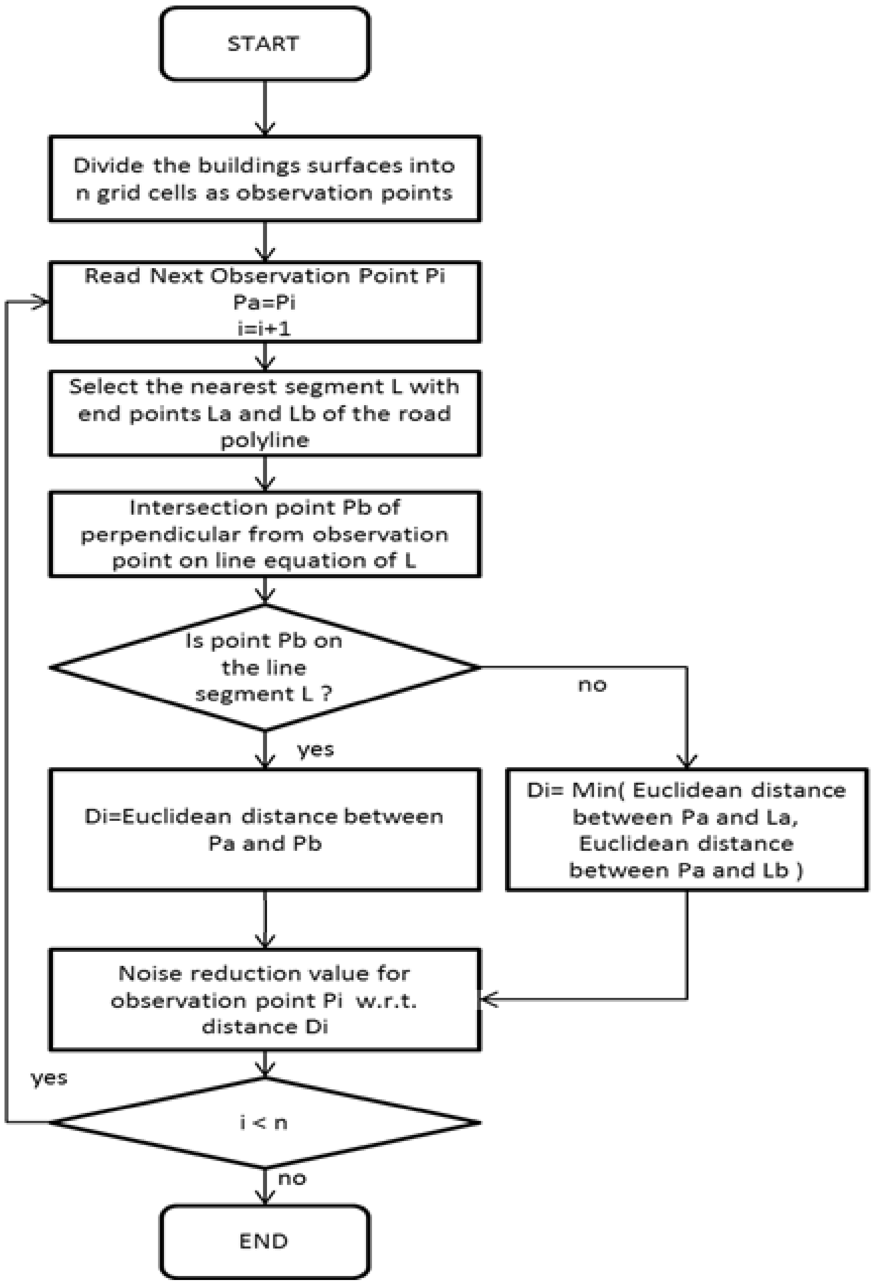

Figure 5.12 3D Traffic Noise Mapping Algorithm

The algorithm considers two cases to find the distance between the observation point and a line segment as below,

Case 1: The intersection point of the perpendicular from the observation point on the line lies between the end points of the line segment.

In this scenario the distance between the point of intersection and the observation is the minimum distance between the line segment and observation.

Case 2: The intersection point of the perpendicular from the observation point on the line lies beyond the end points of the line segment.

In this case the minimum of the distances between the observation point and each end point of the line segment is the minimum distance between the line segment and the observation point.

The center of each grid cell on the wall surface was considered as the observation point and its 3D Euclidian distance was calculated from the road polyline using the algorithm developed. This distance was applied as a noise reduction factor using equation 4-7. The 3D traffic noise map generated as a result of this approach is shown in fig 5.13.Cesium is also equipped with function for temporal visualization of geospatial information. This feature of cesium was utilized to create an animation for the temporal variation in traffic noise level. The graph in fig 5.13 represents this temporal variation.

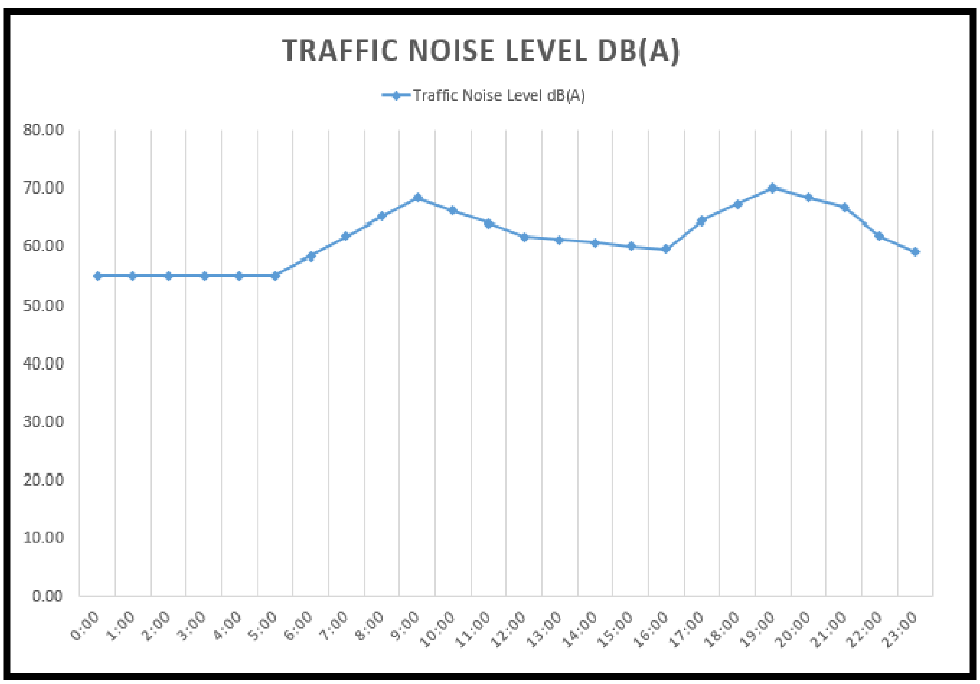

Figure 5.13 Temporal Variation of the Traffic Noise at 10 m distance from the Road Center

Depiction: From the time graph it can be easily depicted that the noise level is highest during 9:00 am in the morning and in the evening at 7:00 pm

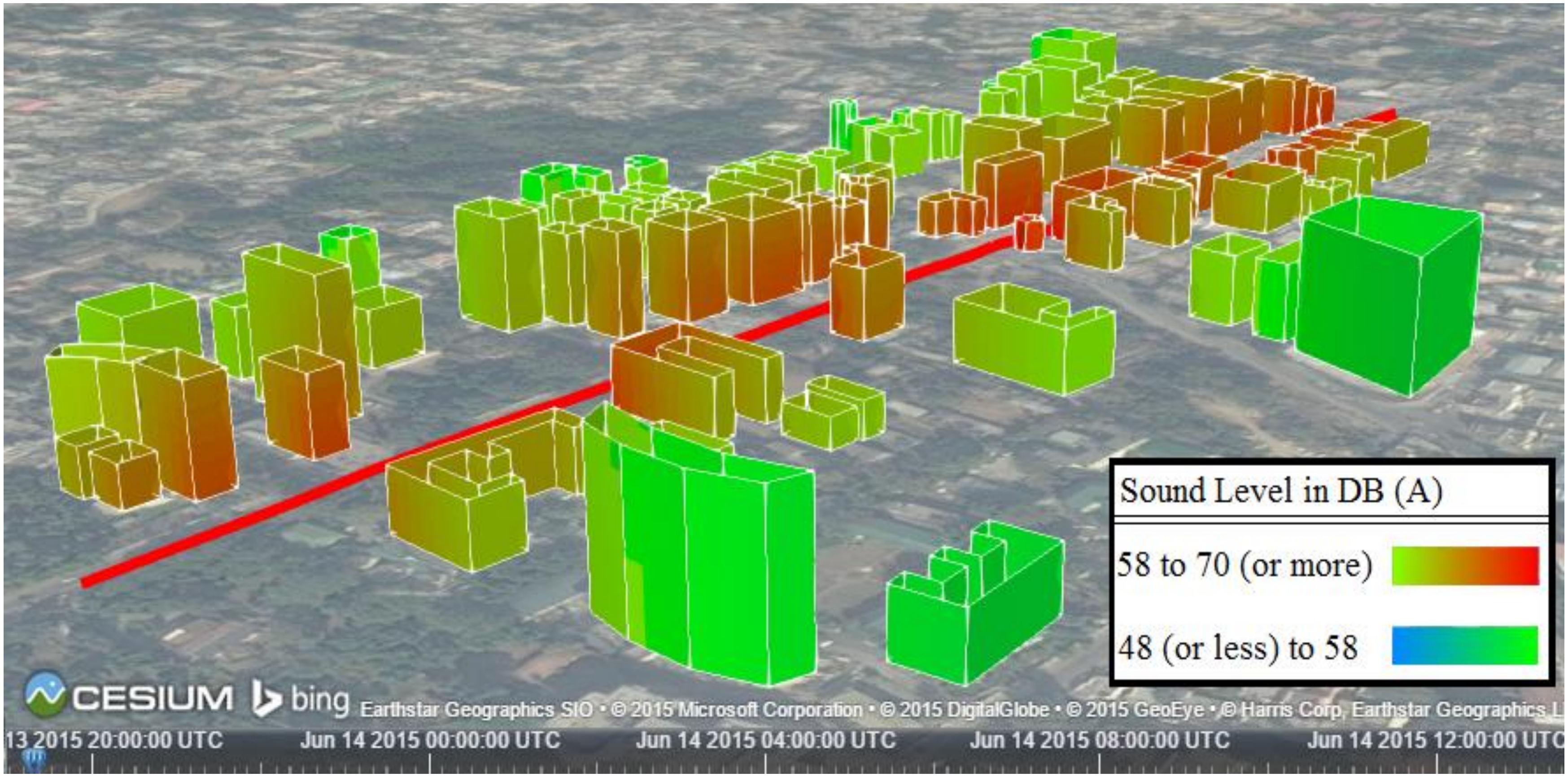

Figure 5.14 3D Traffic Noise Map using Voxel model of the Study Area

5.5.5 Spatio-Semantic Analysis of Traffic Noise

As per the depiction from the time graph, to perform the spatio semantic analysis the traffic noise level at 7:00 were taken consideration.

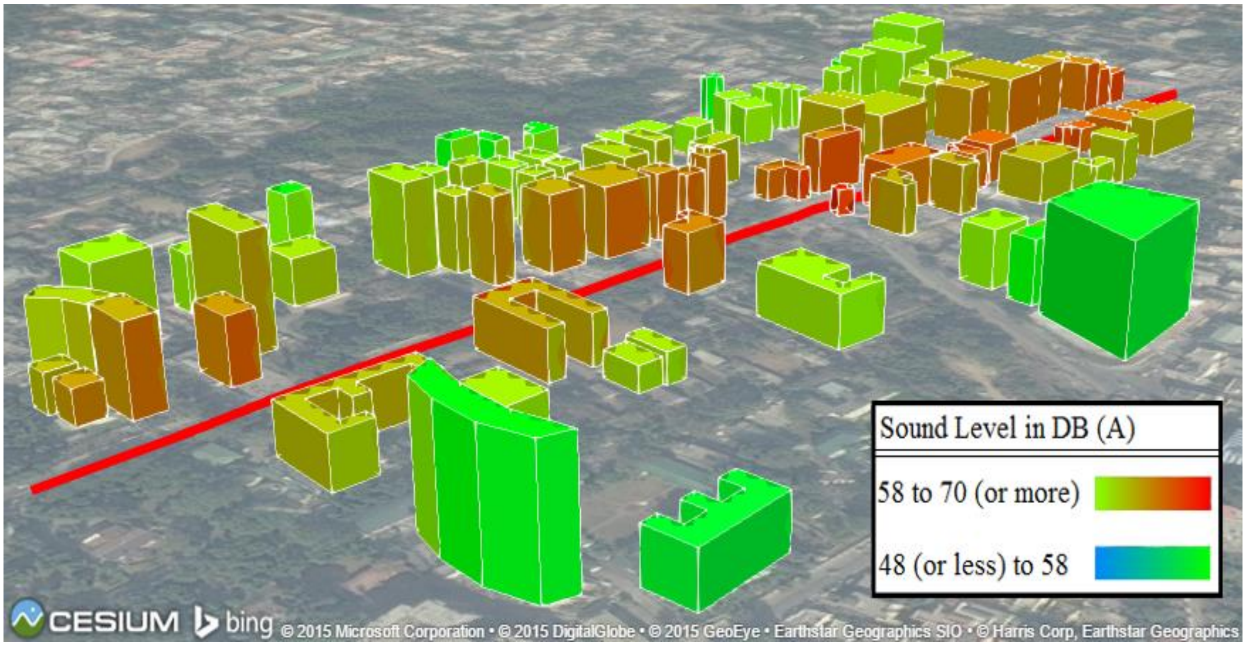

Figure 5.15 Traffic Noise Map generated using the LoD2 CityGML Semantic Model

The traffic noise map generated using the LoD2 CityGML semantic model as shown in figure 5.15. The maximum noise level observed in this case was around 75 dB (A) at a distance of 10 m from the road center. To calculate the average noise level impact on the wall distance of the center point of the wall and roof surface were considered.

A review on the European southern and northern region by (Diaz et al., 2001) depicts the effect of noise on harmful health of people. After carefully reading this document a decision was made to perform the semantic analysis for noise impact greater than or equal to 65 dB (A). To quantify the effect an attempt was made to estimate the number of building surfaces exposed to 65 dB (A) or more. For this, a semantic query was applied on the LoD2 model to retrieve and highlight the building surfaces exposed to 65 dB (A) or more. The result of semantic query is shown in the fig 5.16. The number of wall surfaces identified were 54 in count. From this it can be depicted that a considerable number of people leaving in the vicinity of highway or the heavy traffic road are affected by the high level of traffic noise.

It is essential for planners to analysis the building design and careful take the design decisions to prevent the continuous impact of traffic noise on the people leaving in the vicinity of the road surfaces.

From the semantic query applied, it can be easily identified that some of the buildings has the above threshold noise level impact only on the surfaces that face towards the road. A design decision can be taken to avoid the bedroom, balcony or in some cases the window towards the roadside. Also, for an under construction site, an architect or a planner can apply certain modifications to the site design such that, the resulting model will have lesser impact on the overall site or the susceptible areas of the site.

Table 5.1 Comparison of some indicators for sleep disturbance, between northern and southern Europe(Diaz et al., 2001)

	Nr.	Leq, 8h or 9h in dB(A)	Falling asleep duration	Falling asleep difficulties	Subjective sleep qualitatively	Morning tiredness
Northern Europe	9	54	22 min.	25%	significantly worse	Morning significantly higher
		39	15 min.	2-3%	significantly better	Morning significantly lower
	8	64	44	37%	significantly worse	Morning/daytime significantly higher
		48	25	8%	significantly better	Morning/daytime significantly lower
Southern Europe	1	69,5	not significant	significantly higher (M = 2,03 ± 0,80)	significantly worse (M = 3,40 ± 0,87)	significantly higher (M = 2,85 ± 0,82)
		39,8	not significant	significantly lower (M = 1,85 ± 0,70)	significantly better (M = 3,62 ± 0,81)	significantly lower (M = 2,59 ± 0,83)
	2	52	-	17%	-	-
	14	72,9 and 66,8	-	25%	-	-
		61,1 and 55,8	-	8 %	-	-
		67,9 *	-	27 %	-	-
	16	55	-	25,1 % very much and much	-	-

Figure 5.16 Semantic query for building surface with noise impact >= 65dB (A)

5.5.6 Spatio-Temporal Semantic Analysis

The spatio temporal analysis was performed to estimate the number of roof surfaces and the number of wall surfaces affected with 65 dB (A) or more from the start to the end of the day. The graph in fig 5.17 shows this variation. It can be observed that these numbers increase at around 7:00 pm in the evening and 9:00 am in the morning

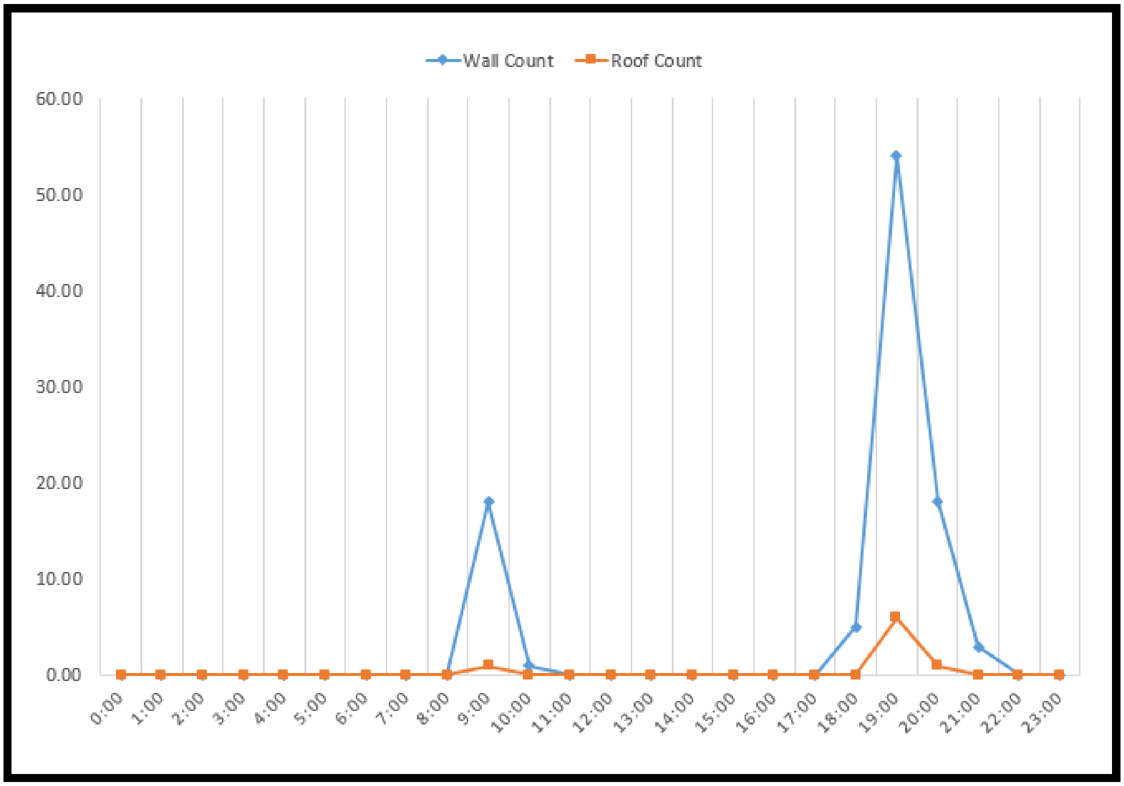

Figure 5.17 Number of Walls and Roofs Affected From start to the end of the day

5.5.7 Voxel Based Traffic Noise Map vs. LoD2 Traffic Noise Maps

The traffic noise maps generated using these two approaches were compared for efficiency and it was found that the voxel abased model is truly 3D in nature whereas, the LoD Traffic Noise Map visualizes the traffic noise at semantic level of details, which means, it has only one representative value for a given semantic feature like a wall. The voxel based model takes much more time for rendering as compared to the LoD2 model. The results of comparison are listed in the table 5.2.

Table 5.2 Voxel Based Traffic Noise Map vs LoD2 Traffic Noise Maps

Voxel Based TNM	**LoD2 TNM**	
1. Relatively Slower as compared with LoD2 TNM	1. Relatively very fast	√
2. Does not consider the semantic nature of urban features	2. Considers the semantic nature of urban features	√
3. Traffic noise levels are estimated at grid level.	3. The noise levels are estimated at semantic level.	√
4. The size of grid can be decided as per the requirements	4. The size and shape of a semantic feature is predefine in the data model	√
5. Truly 3D in nature.	5. Only one value for a semantic feature like a wall.	√
6. The semantic analysis cannot be done hence less applicable to design decision requirements.	6. A sematic query is possible so the model can be used for analysis to take certain design decisions	√

CHAPTER 6

CITYGML ADE FOR ROAD TRAFFIC NOISE

6.1 Review of CityGML Noise ADE

The road traffic noise impacts human health and the quantification of this impact on human health is directly related the building no of inhabitants in the buildings, building surface material and also on the transport system information such as the quantity of vehicles per unit time passing over the road, speed of these vehicles, road surface material etc. The CityGML ADE proposed by iScope project is one of the good example that maps the noise level impact at semantic level using the building information model and the transportation model (De Amicis et al., 2012; Wilson, n.d.). The important attributes of these information models utilized in noise ADE are depicted in the table 6.1.

Table 6.1 CityGML NoiseADE Important Attributes(Wilson, n.d.)

Traffic	**Roads**	**Buildings/Furniture**	**Noise Exposure**
Traffic flow	surface Material	Reflectivity facades	Lden
% Heavy Vehicles	Gradient	height	Lday
Speed limits	Width	Noise barriers	Levening
			Lnight

As a part iScope project various 3D traffic noise maps, contour maps, maps and reports based on the semantic analysis were generated (Wilson, n.d.). Values that are directly derived from the properties of the 3D City Model are Elementary Indicators (EI) (Krüger and Kolbe, 2012). One of such attributes is ‘no of storey’ needed for semantic analysis of traffic noise.

$EI_{\text{Number of Storey}}$ = Property $[\text{Building}]_{\text{numberOfStoreys}}$

Indicators whose values are derived as a function on the geometry of a 3D City Model are complex Indicators (CI) (Krüger and Kolbe, 2012). The geometry of the road segment was derived from the geometry of the transportation complex network.

$CI_{\text{lod0BaseLine}}$ = f (Geometry $[\text{TransportationComplex}]_{\text{lod0Network}}$)

6.2 Identification of Interoperability Gap

6.2.1 Interoperability between BIM and SCM-1

There are several studies (Reza Ranjbar et al., 2012; Schrenk et al., 2008) that followed SCM-1 as a standard for road traffic noise calculation and mapping. SCM-1 methodology takes into account many parameter that are related to building geometry and calculates the ultimate noise level at the observation point. These are the noise level at the source, traffic flow quantity, correction applied at the traffic-light controlled junction, rebound of noise from the building surfaces, correction applied due to distance from the road, correction due to air, ground attenuation etc. (Reza Ranjbar et al., 2012). The traffic noise is an important parameter that is considered during the design and construction phase of the infrastructure.

Existing noise ADE does not support interoperability for all these attributes (Open Geospatial Consortium Inc, 2007). So to support these attributes a workflow process for interoperability between SCM-1 Models and the BIM model must be implemented. As a step in this workflow, an instance document should be generated by the service provider system such that the document accommodates for the attributes of SCM-1 as a result of analysis. After transmission to the service consumer system, this instance document must be validated using the schema generated by the CityGML ADE for traffic noise so that, it can utilized as per the defined standard of interoperability for SCM-1.

To make the results of analysis using the proposed Web GIS framework interoperable, the workflow process as shown in fig 6.1 has been proposed,

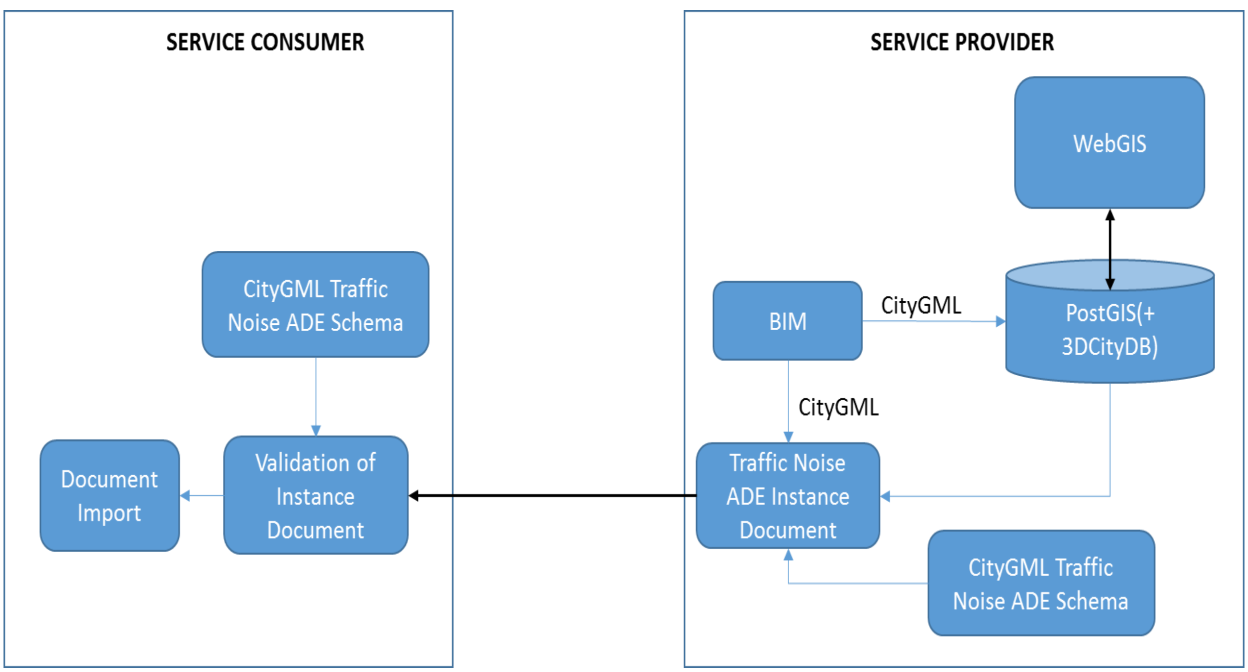

Figure 6.1 Proposed workflow for interoperability

In the proposed workflow the ADE schema works as a contract between all the vendors that support for the SCM-1 model attributes. The instance document is validated at both the consumer and service provide side and only the attributes supported by the CityGML ADE schema are exported between these two systems.

6.2.2 ADE Support for Temporal Simulation

Many scientific processes require spatio temporal variations to be analyzed. Some of these processes includes traffic noise modeling (Reza Ranjbar et al., 2012), Rural-urban Land Conversion (Huang et al., 2009), Urban Air Pollution(Hasenfrat et al., 2014) etc. CityGML 2.0 currently does not support temporal analysis. Instead, it is required to define redundant attributes to support temporal requirement. In case of CityGML noise ADE(Open Geospatial Consortium Inc, 2007), the all the temporally variable attributes are defined four times to show temporal variation during a whole day. But, this scenario fails in cases where there is a short span of time when the noise is very high and it creates a huge impact on health of people exposed to such situation. To cover these scenario, one must define a standard that can support variability during a dynamic time range to cover situations that are highly impactful.

An analysis of the existing CityGML ADE and the SCM-1 model was performed to identify the time dependent attributes. The analysis resulted in the list of attributes that are time dependent and that are time independent. Now, the requirement was to add the multiplicity in the time dependent attributes such that they are defined once for each temporal range. To fulfill this requirement, a data type was identified from the schema of Geometric Markup Language (GML) that is *gml:TimePeriod*. This data type was used to collective represent the extent in time for which the time dependent parameters of road segment and building walls are effective. The location in of a *gml:TimePeriod* is described by the temporal positions of the instants at which it begins and ends. The length of the period is equal to the temporal distance between the two bounding temporal positions.

6.3 UML Based CityGML ADE Mechanism

6.3.1 Advantages of CityGML ADE

The essence of CityGML is that it can be extended to support interoperability of thematic information. The CityGML Application Domain Extension Mechanism serves this purpose of CityGML. Advantages of CityGML ADE mechanism are,

1. Through ADE mechanism, more attributes like the building surface material, number of aged people (age > 60) living inside the building can be added to the existing CityGML data model.
2. New feature types can be added.
3. The ADE can be defined in a way that it extends properties from more than one CityGML modules.
4. The ADE Schema serves as a contract for validation of CityGML instance document among heterogeneous systems involved in the workflow process.

6.3.2 CityGML Profile

UML profile for CityGML has been defined by ISO 19103 standard. The stereotypes defined in this profile are, ApplicationSchema, Leaf, ADEElement, DataType, FeatureType, Type, Union, CodeList, Enumeration, and Import. Once these stereotypes are imported into the resources tab of Enterprise Architect, these can be dragged and dropped to define new elements. <<ApplicationSchema>> represents a package with GML application schema in it. The <<Leaf>> represent a package in the lowest level hierarchy where only the features can be defined. <<FeatureType>> to represent a class that is a feature type which can be extended with an <<ADEElement>>. The schema output generated after the transformation of the class diagram contains gml:AbstractFeatureType with the standard object properties to represent this <<FeatureType>> element. <<DataType>> is generally used to represent the complex values or a collection of properties.

There are two ways an ADE can be defined, either by extending the CityGML features through inheritance or by using the concept of “hook”. Also there are two scenarios in which an ADE can be developed. In both the case the concept of hooks is implemented.

1. Existing feature types are extended to define additional application specific properties. The steps followed are,
   1) An existing <<featureType>> element is used to define new thematic properties.
   2) An <<ADEELement>> is added with a generalization relationship is added to the existing <<featureType>> element.
   3) The new properties are defined in the <<ADEElement>>.

2. When the requirement is to add totally new feature type to the schema. The first two steps are similar to the first scenario. The next step is to add another feature type with an association relationship with the <<ADEElement>>. At last a Generalisation relation of the new feature type is set with AbstractFeature class.

6.3.3 Generation of Schema

Once the UML model has been defined the XMI file can be exported from Enterprise Architect. XMI is the XML metadata interchange format used for interchange of the metadata information for processing and ultimately for creation of xml schema.

This XMI file is then imported into to shapechange v 2.0.0 for processing. ShapeChange is a tool implemented in java and used for UML to GML transformation. The shapechange comes with a configuration file in which the encoding rules for this conversion are defined as per ISO standards. These can be edited as per the application requirement.

Once the configuration file is set, a simple shapechange command with the configuration file as an argument can create the intended CityGML schema.

6.4 Proposed Road Traffic Noise ADE

The attributes to support the SCM-1 models have a direct relation to the geometric attribute of the features of 3D City Model. As per the equations proposed by (Reza Ranjbar et al., 2012), for the variables of SCM-1, variable in equation 4.3 can be defined as complex indicators as below,

CI_{Dd} = f(Geomertry[Building], Geomertry[Road])

CI_{De} = f(Geomertry[Building], Geomertry[Road])

The traffic noise map as shown in fig 5.14 was implemented by initially dividing the building into grids. To do so, the height of the building was calculated by applying a function on the geometry of the building LoD1 Model.

CI_{height} = f(Geomertry[Building])

The proposed traffic Noise ADE is based on these functions and supports all the attributes defined in equation 4.3. As per the identified gap the schema has been proposed to support the temporal variation of the traffic noise. It has attributes for indicating the time duration for the noise level calculations are carried out. So, the analysis can be performed for short span of time or variable amount of time and still it is supported by the ADE for interoperability. The Conceptual schema of the proposed ADE for building and transportation is shown in fig 6.2 and 6.3 respectively.

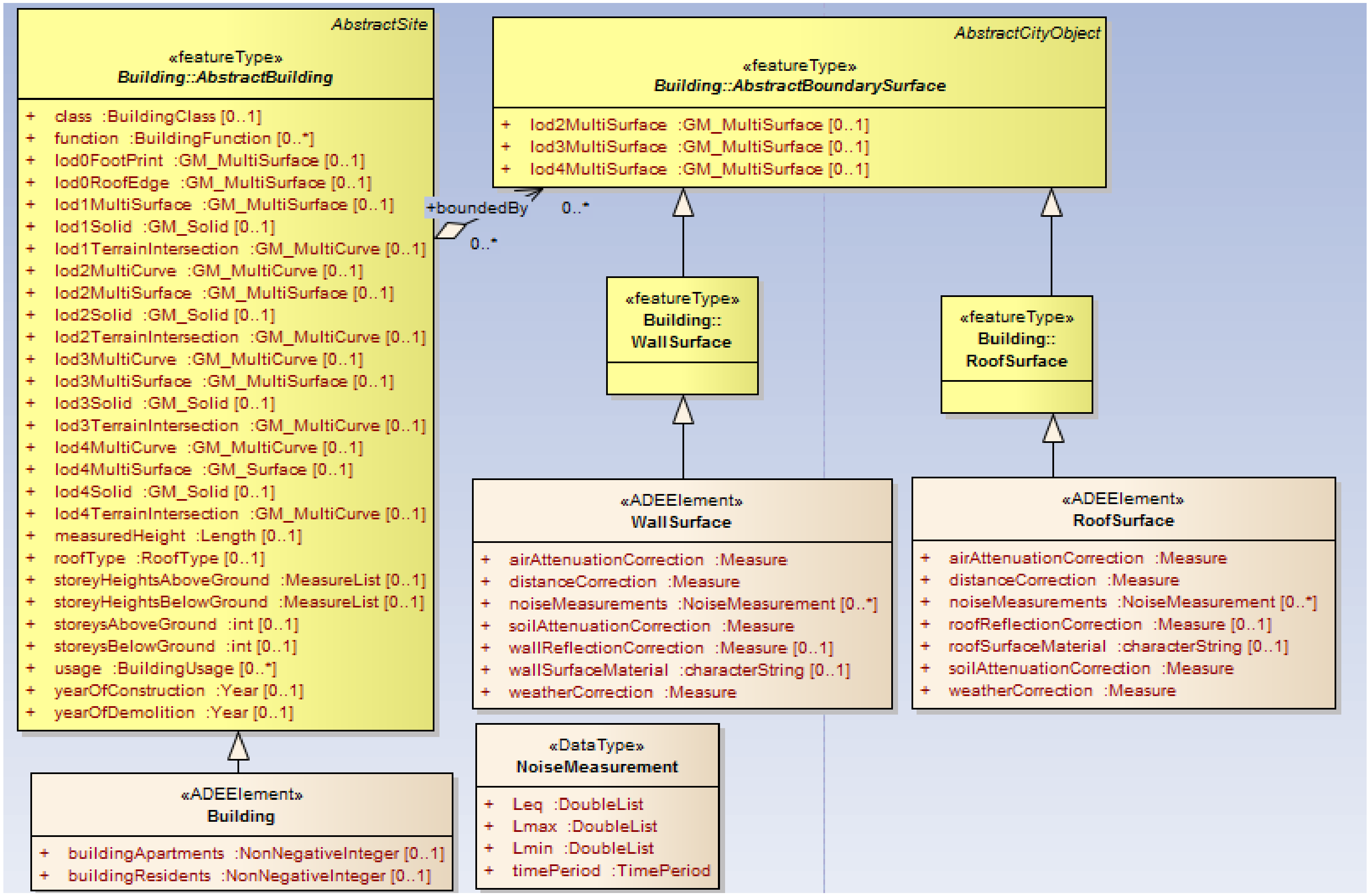

Figure 6.2 Proposed Road Traffic Noise ADE Schema

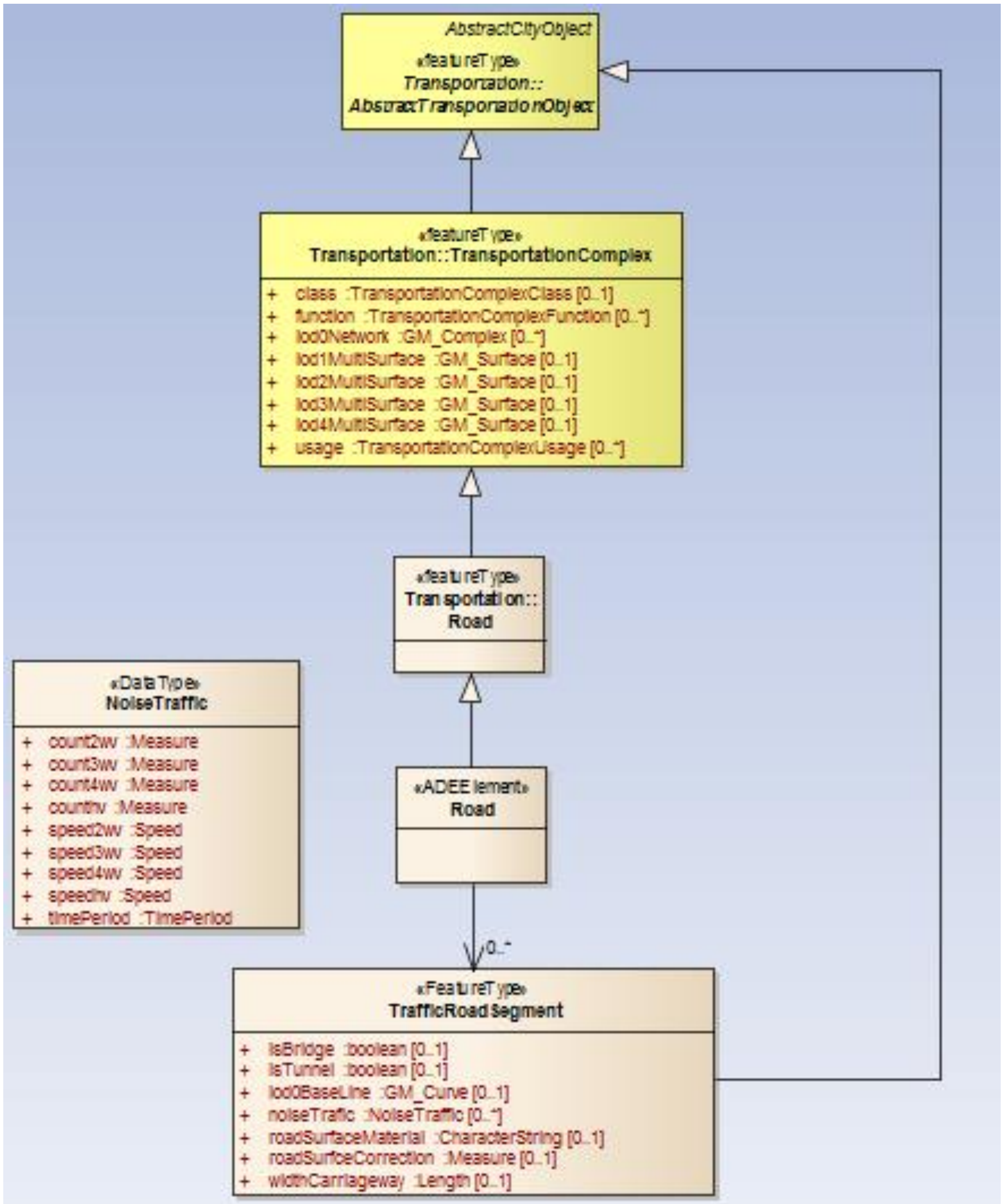

Figure 6.3 Proposed Road Traffic Noise ADE Schema

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The research work was a successful attempt to apply spatio semantic approach for the analysis of 3D urban features using the OGC standards. The study has been applied for the semantic analysis of the urban features to take pre and post construction design and mitigation decisions. A simple traffic noise model was developed that could be applied to the Indian traffic scenario. A simplified approach has been developed for 3D model reconstruction of the urban features. The developed model was successfully transformed into an interoperable data encoding standard supported by OGC. An enterprise application was proposed and implemented to support the geospatial analysis on web. The implemented web GIS architecture was also successfully extended to support the visualization and semantic analysis of urban features. The research work has also proposed a conceptual schema for the integration of SCM-1 traffic noise modeling standard with CityGML data model. The proposed schema allows the time range, for which the analysis is carried out, to be specified dynamically so that the schema is more generalized and applicable for various vendor solutions available for spatio-temporal traffic noise analysis. An instance document generated as a result of analysis applied by the proposed GIS framework, can be validated using the proposed CityGML Traffic Noise ADE schema for a lossless information exchange. With the open source or freely available technology utilized at every step of this research work, it can be concluded that the research work has presented a cost effective web based GIS solution for 3D traffic noise mapping and semantic analysis of traffic noise impacts.

7.2 Answers to Research Questions

What are the open source technologies that fits the requirement of the proposed 3D GIS solution?

The literature review for this work was done to find the relative open source technologies and it was found the cesium is the very good platform that is being adapted by many communities and organizations for research and commercial purposes. Cesium is a javascript library that is capable of rendering 3D scenes on a web globe using the WebGL and Html5. For data storage and management 3DCityDB which is a database schema of PostGIS with a collection of stored procedures and an import export tool. This database schema is based on the CityGML schema. Using importer/exporter tool the CItyGML datasets can be directly imported into this database.

How to integrate the collected geometric information to form an interoperable 3D data model?

To solve this issue, a Google Sketchup plugin was utilized for mapping the 3D model reconstructed into an interoperable CityGML standard.

How to assess the traffic noise model to be used for the roads in the study area?

Different traffic noise models were analyzed and review was performed on these models in accordance with the traffic conditions on Indian roads. The types of different vehicles on Indian roads were categorized and finally a modified version of Calixto model was proposed to support all the identified categories of vehicles.

What are the different cases that should be considered for analysis to match the requirements of the people living along the roadside?

After the literature review on traffic noise effects on health it was identified that the health of people if affected more when the 'A' weighted Leq level is more than 65 dB. So, decision was made to perform the semantic analysis for finding the spatio-temporal extend of the urban features that are affected by 65 dB (A) or more.

How to create an application specific conceptual schema extending the existing schema for CityGML?

An object oriented modeling approach using UML was identified as a suitable method for creation of an interoperable application domain extension to the existing OGC encoding standard that is CityGML 2.0.

7.3 Recommendations

Based on the literature review and the research work conducted, following recommendations can be followed for future work.

- ✓ High resolution satellite Stereo Imagery processing approach can be applied for semiautomatic reconstruction of point cloud for the urban segments. Further the point cloud can be processed using the segmentation and further, a rule based classification approach can be applied for the semantic model reconstruction.
- ✓ LoD3 and LoD4 model models can be reconstructed and analyzed semantically. A semantic analysis of LoD4 models can depict the actual effect of traffic noise on people living inside the building.
- ✓ Other urban features like Pavements, Footpaths, Gardens and Public Places like Railway stations can be analyzed semantically. Analysis tools can be added to the GIS framework for analysis of preventive measures that can be applied like a noise barrier between the road and residential area.
- ✓ A traffic noise model based on SCM-2 methodology can be developed for an accurate measurement of noise levels. And, the CityGML ADE schema can be extended to support the attributes of SCM-2.

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