A project report submitted to the Department of Geospatial and Space Technology in partial fulfillment of the requirements for the award of the degree of:

Bachelor of Science in Geospatial Engineering

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Abstract

Terrorism refers to the use of violent acts to frighten people in an area as a way of trying to achieve a political goal. One of these violent acts has been through the use of explosive devices. Terrorists’ reliance on bombing is not surprising given that bombs provide a dramatic yet fairly easy and often risk free means of drawing attention to the terrorist cause.

This project gives a geographical perspective of a bomb blast through simulation of an explosion and identification of its effect on 3D structures in an urban environment.

The urban environment which formed the study area was Nairobi’s Central Business District. A three dimensional map of this zone was created using footprints derived from google earth images and heights obtained from fieldwork and public sources. ArcGIS ArcMap was crucial during georeferencing and raster-vector conversion whereas 3D visualization was made possible through ArcGIS ArcScene software. Creation of the bomb model was based on Sadovsky’s equation and USA’s Federal Emergency Management Agency’s bomb chart. Modelling of the bomb blast and intersection of affected features also happened via the Arc Scene module. The 7th August 1998 bomb blast served as a benchmark and was the first to be simulated. The subsequent result was then compared to the actual event and associated reports. After authentication of the explosion model, a vulnerable region was identified from media reports to be Parliament buildings and the bomb threat actualized.

Six levels of damage resulted from the bomb blast model. The affected 3D buildings were then imported into Sketch up software and modelled to reflect their realistic homologous pairs on the ground. The output was 3D maps showing buildings features and their corresponding levels of damage. Blast mitigation technologies were then outlined to address the threat and ensure the survivability of the targeted buildings and by extension save human lives.
Acknowledgements

I would like to acknowledge Dr. Siriba, my supervisor for his support and valuable guidance that made the completion of this project possible.

I am also grateful to Oakar Services Ltd for their technical support and provision of the ArcGIS software which formed the back bone of this exercise.

The various relevant government agencies’ websites, scholarly research papers on explosives and documented media reports about bomb blasts have helped me a great deal in understanding my subject matter and I am deeply indebted to them for this wealth of information.

My heart also goes out to Otieno Daniel and Githumbi Joy, last year finalists for aiding me with their reports which has gone a long way in helping me to document my study.

Last but not least I would like to thank the entire staff of the Geospatial and Space Technology department for their encouragements, knowledge and skills that they have ably imparted to me. Without you I would not be a competent geospatial engineer.
Dedications

I would like to dedicate this report to my family: my father Mr. Zachary Masinde and mother Mrs. Jane Masinde, my brothers Victor Baraka and Caleb Otieno and my sisters Mary Osta and Mercy Mmkombe for their prayers, encouragement and support throughout my undergraduate study.

Members of the Intelligence Service who work around the clock and behind the scenes to keep us safe get my salute. You are real life heroes.

I would also like to dedicate this report to the victims of the 7th August 1998 bomb blast. We as a nation will never forget you.
# Table of contents

Abstract ............................................................................................................. ii
Acknowledgements .......................................................................................... iii
Dedication .......................................................................................................... iv
Table of contents .............................................................................................. v
List of Tables ..................................................................................................... vii
List of Figures .................................................................................................... viii
List of Abbreviations and Acronyms ................................................................. x

## 1.0 INTRODUCTION ................................................................................. 1
  1.1 Background ............................................................................................... 1
  1.2 Statement of the problem ........................................................................ 2
  1.3 Objectives of the project ......................................................................... 3

## 2.0 LITERATURE REVIEW ...................................................................... 4
  2.1 3D Geovisualization ................................................................................ 4
      2.1.1 Types of 3D representations used in Geovisualization .................. 4
  2.2 Explosives ................................................................................................ 5
      2.2.1 Nature of Explosives .................................................................... 5
      2.2.2 Results of an Explosion ................................................................ 7
  2.3 Modelling an Explosion .......................................................................... 11
      2.3.1 Bomb mass-energy estimation ...................................................... 11
      2.3.2 Weibull’s formula ......................................................................... 13
      2.3.3 Brode’s method ........................................................................... 14
      2.3.4 Sadovsky’s equation ................................................................... 15
      2.3.5 Computer programs .................................................................... 16

## 3.0 METHODOLOGY AND STUDY AREA ........................................... 17
  3.1 Study Area: Nairobi CBD ....................................................................... 17
  3.2 Tools and Materials ................................................................................ 18
      3.2.1 Software ...................................................................................... 18
      3.2.2 Hardware .................................................................................... 19
      3.2.3 Flow chart .................................................................................. 20
  3.3 Data collection ........................................................................................ 21
      3.3.1 Nairobi CBD Raster layer ............................................................. 21
      3.3.2 Georeferencing .......................................................................... 21
      3.3.3 Digitization ................................................................................. 24
  3.4 Data Analysis .......................................................................................... 26
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4.1</td>
<td>Defining the Bomb’s Parameters</td>
<td>26</td>
</tr>
<tr>
<td>3.4.2</td>
<td>Intersecting the threat domes with the building features</td>
<td>29</td>
</tr>
<tr>
<td>3.4.3</td>
<td>Prediction of a bomb blast</td>
<td>33</td>
</tr>
<tr>
<td>3.4.4</td>
<td>Creating realistic three dimensional objects</td>
<td>34</td>
</tr>
<tr>
<td>4.0</td>
<td>RESULTS AND DISCUSSION</td>
<td>37</td>
</tr>
<tr>
<td>4.1</td>
<td>Nairobi CBD 3D City model</td>
<td>37</td>
</tr>
<tr>
<td>4.1.1</td>
<td>Perspective view of the 3D City model</td>
<td>37</td>
</tr>
<tr>
<td>4.1.2</td>
<td>Immersive View of the 3D City model</td>
<td>39</td>
</tr>
<tr>
<td>4.2</td>
<td>Post 7th August 1998 bomb blast Levels of Damage</td>
<td>41</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Level 1</td>
<td>42</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Level 2</td>
<td>44</td>
</tr>
<tr>
<td>4.2.3</td>
<td>Level 3</td>
<td>45</td>
</tr>
<tr>
<td>4.2.4</td>
<td>Level 4</td>
<td>47</td>
</tr>
<tr>
<td>4.2.5</td>
<td>Level 5</td>
<td>48</td>
</tr>
<tr>
<td>4.2.6</td>
<td>Level 6</td>
<td>50</td>
</tr>
<tr>
<td>4.3</td>
<td>Authentication of the 7th August 1998 bomb blast model</td>
<td>51</td>
</tr>
<tr>
<td>4.4</td>
<td>Simulated bomb attack near Parliament buildings</td>
<td>52</td>
</tr>
<tr>
<td>4.4.1</td>
<td>Level 1</td>
<td>53</td>
</tr>
<tr>
<td>4.4.2</td>
<td>Level 2</td>
<td>54</td>
</tr>
<tr>
<td>4.4.3</td>
<td>Level 3</td>
<td>55</td>
</tr>
<tr>
<td>4.4.4</td>
<td>Level 4</td>
<td>56</td>
</tr>
<tr>
<td>4.4.5</td>
<td>Level 5</td>
<td>57</td>
</tr>
<tr>
<td>4.4.6</td>
<td>Level 6</td>
<td>50</td>
</tr>
<tr>
<td>4.5</td>
<td>Blast Mitigation Practices</td>
<td>61</td>
</tr>
<tr>
<td>4.5.1</td>
<td>Site and layout design</td>
<td>61</td>
</tr>
<tr>
<td>4.5.2</td>
<td>Building Design standards</td>
<td>62</td>
</tr>
<tr>
<td>4.5.3</td>
<td>Fire suppression, Utilities and Life Support systems</td>
<td>63</td>
</tr>
<tr>
<td>5.0</td>
<td>CONCLUSION AND RECOMMENDATIONS</td>
<td>64</td>
</tr>
<tr>
<td>5.1</td>
<td>Conclusion</td>
<td>64</td>
</tr>
<tr>
<td>5.2</td>
<td>Recommendations</td>
<td>65</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>66</td>
<td></td>
</tr>
</tbody>
</table>
List of Tables

Table 2.1: 2D versus 3D visualization....................................................4
Table 2.2: Calculated parameters of the mixtures of AN based Fertilizer........12
Table 3.3: Publicly available building heights............................................24
Table 3.2: Damage Approximation Chart.................................................27
Table 3.3: Levels of damage and associated blast pressures......................28
Table 4.1: Levels of Damage, associated blast pressures and radii of influence....42
Table 4.2: Buildings with level 1 damage.................................................44
Table 4.3: Buildings with level 2 damage.................................................45
Table 4.4: Buildings with level 3 damage.................................................47
Table 4.5: Buildings with level 4 damage.................................................48
Table 4.6: Buildings with level 5 damage.................................................50
Table 4.7: Predicted levels of damage, associated blast pressures and radii of influence.................................................................53
Table 4.8: Buildings likely to have level 1 damage....................................54
Table 4.9: Buildings likely to have level 2 damage ....................................55
Table 4.10: Buildings likely to have level 3 damage...................................56
Table 4.11: Buildings likely to have level 4 damage...................................57
Table 4.12: Buildings likely to have level 5 damage...................................58
List of Figures

Fig 2.1: An explosion as a bubble.................................................................6
Fig 2.2: Blast pressure wave........................................................................7
Fig 2.3: Interaction of a blast wave and the built environment......................8
Fig 2.4: Building damaged by a blast............................................................9
Fig 2.5: Bombed US Embassy. Note the structural Integrity........................10
Fig 2.6: Bomb Threat Standoff Chart........................................................13
Fig 2.7: Eblast result interface.................................................................16
Fig 3.1: Nairobi CBD 2D map....................................................................17
Fig 3.2: Google Earth Image showing the Nairobi CBD aoi........................21
Fig 3.3: Extracting Earth information from google earth image..................22
Fig 3.4: Placement marks...........................................................................22
Fig 3.5: Georeferencing............................................................................23
Fig 3.6: Nairobi CBD raster.......................................................................23
Fig 3.7: Digitizing the Times Tower..........................................................25
Fig 3.8: August 7th 1998 bomb epicenter.................................................25
Fig 3.9: Bomb attributes..........................................................................26
Fig 3.10: Extrusion using the height attribute............................................29
Fig 3.11: Converting buildings to multipatch features..............................30
Fig 3.12: Using Is Closed 3D.................................................................30
Fig 3.13: Open features...........................................................................31
Fig 3.14: Use of the Union 3D.................................................................31
Fig 3.15: Threat dome dimensions for level 1..........................................32
Fig 3.16: Intersection.............................................................................33
Fig 3.17: the most probable epicenter ...................................................34
Fig 3.18: Converting the multipatch layer into collada files.....................35
Fig 3.19: Using Sketch Up to model the Min. of Foreign Affairs...............36
Fig 3.20: Ministry of Foreign Affairs in ArcScene...................................36
Fig 4.1: Nairobi CBD perspective view1...............................................37
Fig 4.2: Nairobi CBD perspective view2 ................................................. 38
Fig 4.3: Nairobi CBD perspective view3 ................................................. 38
Fig 4.4: Nairobi CBD perspective view4 ................................................. 39
Fig 4.5: Office of the Deputy President .................................................... 39
Fig 4.6: Parliament .............................................................................. 40
Fig 4.7: Protection Building and Laptrust House ..................................... 40
Fig 4.8: View of the CBD from Uhuru Park .............................................. 41
Fig 4.9: US Embassy, Cooperative House and sandwiched Ufundi House before the bomb blast ................................................................. 41
Fig 4.10: Level 1 Threat dome (Perspective view1) .................................... 43
Fig 4.11: Level 1 Threat dome (Perspective view2) .................................... 43
Fig 4.12: Level 2 Threat dome (Perspective view1) .................................... 44
Fig 4.13: Level 2 Threat dome (Perspective view2) .................................... 45
Fig 4.14: Level 3 Threat dome (Perspective view1) .................................... 46
Fig 4.15: Level 3 Threat dome (Perspective view2) .................................... 46
Fig 4.16: Level 4 Threat dome (Perspective view1) .................................... 47
Fig 4.17: Level 4 Threat dome (Perspective view2) .................................... 48
Fig 4.18: Level 5 Threat dome (Perspective view1) .................................... 49
Fig 4.19: Level 5 Threat dome (Perspective view2) .................................... 49
Fig 4.20: Level 6 Threat dome ............................................................... 51
Fig 4.21: Predicted Level 1 Threat dome .................................................. 54
Fig 4.22: Predicted Level 2 Threat dome .................................................. 55
Fig 4.23: Predicted Level 3 Threat dome .................................................. 56
Fig 4.24: Predicted Level 4 Threat dome .................................................. 57
Fig 4.25: Predicted Level 5 Threat dome .................................................. 58
Fig 4.26: Predicted Level 6 Threat dome .................................................. 60
List of abbreviations

AN…………………………Aluminium Nitrate
ANFO……………………..Aluminium Nitrate Fuel Oil
CAN……………………….Calcium Ammonium Nitrate
FEMA……………………..Federal Emergency Management Agency
LOD……………………..Level of Detail
TNT……………………..Trinitrotoluene
US……………………….United States
CHAPTER 1: INTRODUCTION

1.1 Background

3D mapping/visualization is a technology that creates three dimensional views of natural and man-made features and realistically represents them on a map for better analysis and decision making. It provides an effective way of presenting large amounts of complex information to a wide audience, including those with no GIS or mapping experience since it allows the user to easily relate the information to reality. (Oloo, 2015)

3D mapping has wide applications in a number of industries including urban planning, architecture, engineering design, intelligence and defense, disaster management, scientific and medical research. The use of 3D mapping technology for disaster management was well illustrated in 2007 during the containment of a carcinogenic steam pipe explosion in Mid-Manhattan, USA where it helped the city authorities to identify portions of buildings affected by the explosion. (ArcGIS guide book)

An explosion is defined as a large-scale, rapid and sudden release of energy. (T. Ngo, P. Mendis, A. Gupta & J. Ramsay, 2007). It is always accompanied by an increase in the volume of surrounding matter in an extreme way, usually with the generation of high temperatures. This sudden release of energy may be in a physical, chemical or nuclear manner. In physical explosions, energy is released when a vessel containing a pressurized liquid is ruptured. Chemical explosions occur due to the rapid oxidation of fuel elements (carbon and hydrogen atom) while nuclear explosions are caused by the redistribution of protons and neutrons within interacting nuclei.

The shock wave created by an explosion can propagate through any medium, or in the absence of a material medium, through an electromagnetic field. Furthermore, the detonation of a condensed high explosive generates a tremendous amount of energy (hot gases under pressure of up to 300 kilo bar and a temperature of about 3000-4000°C). This makes them useful in a wide variety of Industrial applications such as breaking hard rocks during mining and construction, demolishing defunct buildings, controlling avalanches in the Alps, aiding oil and gas exploration, visual effects in the entertainment industry and lighting up the sky during firework ceremonies.
However, on the flipside, the destructive power of explosives has been harnessed for a negative cause usually in the name of terrorism. Urban regions have borne the brunt of such attacks. One such attack on the seventh of August 1998 in Nairobi took the lives of 218 innocent people and injured several thousand others. Other notable examples of destruction caused by terrorist bombs in the last decade include explosions in the financial center of London, a multistory Jewish community center in Buenos Aires, the Alfred P Murrah federal building in Oklahoma City and the Khobar Towers in Saudi Arabia.

1.2 Statement of the problem

The use of explosives for terrorist purposes (Bombings) account for nearly half (46 percent) of all international terrorist attacks carried out since 1968, a proportion that has rarely fallen below 40 percent or exceeded 50 percent in any year (Center for the Study of Terrorism and Political Violence). Few skills are required to manufacture a crude bomb, surreptitiously plant it, and then be miles away when it explodes. These attacks typically involve only one or two persons and, in general, do not require the same organizational expertise, logistics, and knowledge required of more sophisticated operations such as kidnapping, barricade and hostage situations, assassination, or assaults against defended targets.

A bomb explosion within or immediately near a building brings catastrophic effects such as the destruction of the building's external and internal structural framework, collapsing walls, blowing out large expanses of windows and shutting down critical fire-and-life-safety systems (i.e. fire detection and suppression, ventilation, light, water, sewage, and power). Loss of life and injuries to occupants can result from many causes, including direct blast-effects, debris impact, fire, and smoke. The indirect effects can combine to inhibit timely evacuation, thereby contributing to additional casualties.

Due to such disastrous effects, there is need to develop a suitable spatial model that will demonstrate the effects of such a blast in a target’s neighbourhood and thence forth answer a number of questions. For example, which buildings are likely to be
affected by a terrorist bomb attack based on their spatial distance from the main target structure? Why are some buildings which are far away from the explosion foci damaged more than buildings at the blast’s epicenter? What standard should guide insurance premium rates paid by property owners whose structures border potential target sites? What measures should property owners take to protect their lives and investments from sudden destruction?

Recent terrorist attacks against urban buildings dramatically illustrate the influence of bomb placement and building design on the nature and extent of direct structural damage. A bomb’s damage to buildings depends not only on the building’s construction criteria and the strength of the bomb but also on their location relative to the blast’s epicenter. A good case point is the 7th August 1998 bomb attack on the US Embassy in Nairobi, Kenya. Although the main target of the blast was the American Embassy, most of the adjacent buildings such as Ufundi house bore the brunt of this attack in terms of structural failure and its occupants got injuries or worse off paid the ultimate prize.

Thus the main problem under study in this project is the lack of a model to advice on an explosive’s spatial reach and more specifically with regards to the 7th August 1998 incident closer at home. This project looks into this problem, validates the historical 1998 blast by carrying out geospatial analysis and then creates a model which can further be used to deter or alleviate any future bomb terror in the city.

1.3 Objectives of the project

The main objective of this project is:

- To identify a bomb blast’s levels of damage in a 3D urban environment.

The specific objectives include:

i. To create a 3D map of Nairobi City’s Central Business District
ii. To model 3D geographical threat domes of a bomb blast
iii. To simulate a bomb attack on a vulnerable site within the CBD
iv. To recommend blast mitigation practices
CHAPTER 2: LITERATURE REVIEW

2.1 3D Geovisualization

Geovisualization refers to the use of visual geospatial displays to explore data and through that exploration come up with hypothesis, problem solutions and construct knowledge (Kraak, 2003). Since the advent of cartography, visualization of geographic information have largely depended on the two dimensional view of data. Nowadays, rapid development of computer graphics has allowed also the production of maps in 3D virtual environments.

Table 2.1 2D versus 3D Visualization (source: Oloo, 2015)

<table>
<thead>
<tr>
<th>2D visualization</th>
<th>3D visualization</th>
</tr>
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<tbody>
<tr>
<td>Provides a good interpretation of distances</td>
<td>Interpretation of distances more difficult</td>
</tr>
<tr>
<td>Provides a good overview and a static orientation</td>
<td>Orientation more difficult since the image position can always be changed.</td>
</tr>
<tr>
<td>High mental effort is required for symbol interpretation; most symbols in 2D mapping are composed of abstract shapes</td>
<td>Provides a more realistic view of the physical and the built environment</td>
</tr>
<tr>
<td>In 2D visualization, a legend is needed for proper interpretation of map symbols</td>
<td>3D visualization can work without a legend</td>
</tr>
</tbody>
</table>

2.1.1 Types of 3D representations used in Geovisualization.

3D Symbols

3-Dimensionals can be used even on 2D maps to communicate to non-expert map readers about geographic objects in a particular area. For example, 3D tree symbols can be used on a 2D map to show the distribution of individual trees in a particular landscape.
3D objects

3D objects can be modeled and represented in three dimensional maps. For instance a city model can be created to represent actual 3D models of houses that should ultimately be built in the landscape. In this case the height of the model buildings can be obtained from publicly available architectural records or estimated as 3m per floor/story. This is because the height of each floor is based on the ceiling height of the room plus the thickness of the floors between each plane which when added totals up to three metres. (Nairobi City County)

3D objects in a city model can be represented at 4 levels of Detail (LODs). LOD1 refers to a 3D model whose objects are purely extruded footprints. LOD2 allow for a degree of similarity between the real feature on the ground and its mapped representative. LOD3 presents architecturally exquisite structures while LOD4 shows the interior of the 3D buildings.

3D surfaces

Using surface modeling techniques, surfaces can be interpolated either from the topographical attributes or from the statistical attributes of data and presented in 3D. For instance, digital elevation models can be represented as 3D surfaces.

2.2 Explosives

Due to the instability of explosives and their potential threat to the public in the hands of the ignorant as well as those who would inflict harm, publicly available literature on their exact effects is restricted. Despite these restrictions, an attempt was made to study explosives and identify the physics behind their operation.

2.2.1 Nature of an explosion

An explosive material, also called an explosive, is a reactive substance which contains a great amount of potential energy that can produce an explosion. Explosions originating from high explosives e.g. TNT create detonations while those that are brought about by low explosives such as gun powder result to the milder deflagration.
Deflagrations travel at subsonic speeds and thus can be easily controlled. Detonations on the other hand travel via supersonic pressure fronts making them highly potent and difficult to manage.

When a high order chemical explosion is initiated, a very rapid exothermic reaction occurs. As the reaction progresses, the solid or liquid explosive material is converted into a very hot, dense, high-pressure gas. These gases exert immense pressure on the atmosphere creating a shock wave in the process. A shock wave consists of highly compressed air, traveling radially outward from the source at supersonic velocities. It can be visualized as a “bubble” that expands until reaching equilibrium with the surrounding air. *(FEMA 426)*

![Fig 2.1: An explosion as a ‘bubble’ (source Trinity, 1945)](image)

This mass of expanding gas (shock wave) rolls outward in a circular pattern from the point of detonation like a giant wave, weighing tons, smashing and shattering any object in its path. The further the pressure wave travels from the point of detonation, the less power it possesses until, at a great distance from its creation, it dwindles to normal atmospheric pressure. As the shock front pressure decays back to ambient pressure, a negative pressure phase occurs that is usually longer in duration than the positive phase. During such a negative phase, a partial vacuum is created and air is
sucked in. This is also accompanied by high suction winds that carry the debris for long distances away from the explosion source.

![Blast Pressure wave](source: frontiers, 2011)

### 2.2.2 Results of an explosion

The detonation of explosives produces three primary effects: blast pressure, fragmentation, and an incendiary or thermal effect. The blast pressure effect is the most powerful and destructive of the explosive effects and thus, the main cause of structural failure in buildings. It is analogous to the stomping action on a box, except that instead of it being a foot, it is a wave that exerts pressure on and around the entire structure for less than a second. The pressures it exerts on building surfaces may be several orders of magnitude greater than the loads for which the building is designed. The shock wave also acts in directions that the building may not have been designed for, such as upward on the floor system. In terms of sequence of response, the blast wave first impinges on the weakest point in the
vicinity of the device closest to the explosion, typically the exterior envelope of the building. The explosion pushes on the exterior walls at the lower stories and may cause wall failure and window breakage. As the shock wave continues to expand, it enters the structure, pushing both upward and downward on the floors. Floor failure is common in large-scale vehicle-delivered explosive attacks, because floor slabs typically have a large surface area for the pressure to act on and a comparably small thickness (FEMA).

Fig 2.3: Interaction of a blast wave and the built environment. (FEMA, 2003)

Explosive pressures decay extremely rapidly with distance from the source. Therefore, the damages on the side of the building facing the explosion may be significantly more severe than on the opposite side. As a consequence, direct blast damages tend to cause
more localized damage. In an urban setting, however, reflections off surrounding buildings can increase damages to the opposite side.

![Building damaged by a blast](Fig2.4: Building damaged by a blast (Aleppo, Syria – 2013 © Hannah Lucinda Smith)

The box is not always crashed. If it is a reinforced box, the force may be insufficient to crush it. Also, if the box is filled with sufficiently strong material, or if the acting force is weak, the box may not crash.

The same principles apply with a building. If the building is reinforced, it may not collapse. If the windows and doors are either open or quickly break out then the pressure on the outside wall may have less effect because of high pressures rushing into the building thus filling it with a counter balancing force.
It is important to note that the line of sight rationale does not apply to blast waves. The fact that the point of explosion cannot be seen by no means implies that the blast effect will not be felt. Blast waves can easily bend or diffract around apparent obstructions.

Fragmentation results from debris such as shards of window glass, bricks, soil being mobilized by the blast. These materials can penetrate walls, break windows and even cause structural damage. Airborne glass fragments typically cause penetration or laceration-type injuries. Larger fragments may cause non-penetrating, or blunt trauma and injuries. In the bombing of the Murrah Federal Building in Oklahoma City, for instance, 40 percent of the survivors in the Murrah Federal Building cited glass as contributing to their injuries. Within nearby buildings, laceration estimates ranged from 25 percent to 30 percent. Fragments were also the main cause of injuries during the 7th August 1998 bomb blast. The glass windows of the adjacent 25-story Cooperative Bank building shattered from the pressure of the blast, killing 10 people instantly and blinding or otherwise mutilating more than 200 others. Fragments are more potent to human beings than to buildings and are thus used as antipersonnel weapons in the military.

The incendiary thermal effect produced by the detonation of high explosives varies greatly from one explosive to another. In general, a high explosive will produce a short
(fractions of a second) bright flash or fireball at the instant of detonation. Unless highly combustible materials are involved, the thermal effect plays an insignificant part in an explosion. Should highly combustible materials be present and a fire is started, the debris resulting from the explosion may provide additional fuel and contribute to spreading the fire. They then can affect the properties of building materials by causing materials to lose flexibility, which may contribute to the structure’s progressive collapse.

2.3 Modelling an explosion

All blast parameters are primarily dependent on the amount of energy released by a detonation in the form of a blast wave and the distance (standoff distance) from the explosion epicenter. As was seen before, the blast wave is assumed to be spherical. Energy from a blast decreases rapidly over distance.

2.3.1 Bomb mass-energy estimation

TNT equivalent is a standard method of quantifying the energy released in an explosion. A ton of TNT is a unit of energy equal to 4.184 gigajoules.

Aluminum nitrate (AN) is a common material used in many homemade bombs. It is easily available as fertilizer in the agricultural sector. The explosive properties of AN on its own are relatively low, but its mixtures with fuels make it typically volatile. For example mixtures of AN and mineral oils (called ANFO explosives) are used mainly in mining; mixtures of AN and aluminum powder, named ammonals, are used for some technical purposes. A way of making more troublesome explosives from fertilizers containing AN is manufacturing mixtures of AN and inert materials like: limestone, dolomite, anhydrite etc. – such fertilizers are called CAN.

Explosives made from mixtures of AN were used by offenders and terrorists in the Murray Federal Building and US embassy-Kenya bombing.
Thus, in case the bomb is AN based, the mass of its ingredients and their respective heat of explosion shown in the table below can be used to calculate the equivalent TNT mass of the bomb.

Table 2.2 Calculated parameters of the mixtures of AN based fertilizers and fuels by D. Buczkowski, 2011

<table>
<thead>
<tr>
<th>Material</th>
<th>Heat of explosion (KJ/Kg)</th>
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<tbody>
<tr>
<td>TNT</td>
<td>4188</td>
</tr>
<tr>
<td>AN</td>
<td>1592</td>
</tr>
<tr>
<td>ANFO</td>
<td>3890</td>
</tr>
<tr>
<td>AN/DOLOMITE 90/10 + DIESEL OIL</td>
<td>3234</td>
</tr>
<tr>
<td>AN/DOLOMITE 80/20 + DIESEL OIL</td>
<td>2706</td>
</tr>
<tr>
<td>AN/DOLOMITE 70/30 + DIESEL OIL</td>
<td>2163</td>
</tr>
<tr>
<td>AN/DOLOMITE 60/40 + DIESEL OIL</td>
<td>1613</td>
</tr>
<tr>
<td>AN/DOLOMITE 50/50 + DIESEL OIL</td>
<td>1071</td>
</tr>
<tr>
<td>AN + AL</td>
<td>6712</td>
</tr>
<tr>
<td>AN/DOLOMITE 90/10 + AL</td>
<td>5954</td>
</tr>
<tr>
<td>AN/DOLOMITE 80/20 + AL</td>
<td>5269</td>
</tr>
<tr>
<td>AN/DOLOMITE 70/30 + AL</td>
<td>4505</td>
</tr>
<tr>
<td>AN/DOLOMITE 60/40 + AL</td>
<td>3713</td>
</tr>
<tr>
<td>AN/DOLOMITE 50/50 + AL</td>
<td>2891</td>
</tr>
</tbody>
</table>

If the bomb’s materials are unknown, its mode of delivery can be used to estimate its size and thence calculate its TNT equivalent mass.

For design purposes, depending on the size and capacity of the vehicle used to deliver the weapon, large-scale truck are estimated to contain 10,000 pounds or more of TNT equivalent. Vehicle bombs that utilize vans down to small sedans typically contain 4,000 to 500 pounds of TNT equivalent, respectively. A briefcase bomb is approximately 50 pounds, and a pipe bomb is generally in the range of 5 pounds of TNT equivalent. This is illustrated below in the US Department of Homeland Security chart.
Fig 2.6: Bomb Threat Standoff Chart

Once the mass of the bomb is known, the blast overpressure can then be calculated.

2.3.2 Weibull’s Formula

One way of determining overpressure is by using Weibull’s formula;

\[ \Delta p = 2410 \left( \frac{m}{v} \right)^{0.72} \]

Whereby:

2410 is a constant based on 1 bar (100kPa)

M is the net explosive mass calculated using all explosive materials and their relative effectiveness
V is the volume of a given area.

The volume is limited to an enclosed space and thus proves to be its Achilles’ heels. Thus, it cannot be used to model blast pressure effect over a large open geographical area.

### 2.3.3 Brode’s method

Another method of estimating peak overpressure due to spherical blast is based on scaled distance Z and was introduced by Brode (1955) as:

\[
\Delta p = \frac{6.7}{z^3} + 1 \text{bar} \ (\Delta p > 10 \text{ bar})
\]

\[
\Delta p = \frac{0.975}{z} + \frac{1.455}{z^2} + \frac{5.85}{z^3} - 0.019 \text{bar} \ (0.1 < \Delta p < 10 \text{ bar})
\]

Scaled distance Z is given by:

\[
Z = (\frac{R}{W})^{1/3}
\]

Whereby:

R is the standoff distance

W is the weight of the explosive in Kg.

However, if the blast wave encounters an obstacle perpendicular to the direction of propagation, reflection increases the overpressure to a maximum reflected pressure \( Pr \) as:

\[
Pr = 2\Delta p\left(\frac{7p_0 + 4\Delta p}{7p_0 + \Delta p}\right)
\]

Where

\( P_0 \) is the ambient atmospheric pressure.

This maximum reflected pressure will only be applied to buildings that are perpendicular to the blast path. The disadvantage with this method is the huge number
of calculations that one would have to undertake, especially if the area of interest lies within a densely populated area such as a city. Furthermore, only the peak overpressure will be accurately calculated.

2.3.4 Sadovsky Formula

There is a common set of equations that can be used for calculation of blast wave from explosive charges, it's called Sadovsky formulas. It works regardless of nature of explosion and depends only on TNT equivalent of explosive charge. All this calculations are based on energy similarity law for explosions which state that all blast wave parameters are function of two variables: first is explosion energy and second is distance from explosion origin.

Sadovsky formula for blast wave from TNT explosion in open air at standard atmospheric pressure 1 atm and standard air temperature:

\[ \Delta p_1 = 0.84 \left( \frac{\sqrt[3]{m}}{r} \right) + 2.7 \left( \frac{\sqrt[3]{m^2}}{r^2} \right) + 7.0 \left( \frac{m}{r^3} \right) \]

The above formula can be modified to represent an explosion at ground level/on earth’s surface at standard atmospheric pressure 1 atm and standard air temperature:

\[ \Delta p_1 = 0.95 \left( \frac{\sqrt[3]{m}}{r} \right) + 3.9 \left( \frac{\sqrt[3]{m^2}}{r^2} \right) + 13.0 \left( \frac{m}{r^3} \right) \]

Whereby
\[ \Delta p_1 = \text{blast overpressure in atm} \]
\[ m = \text{TNT mass equivalent of explosive in kg} \]
\[ r = \text{distance from explosive in metres} \]

This set of equations allow you to determine a blast wave’s overpressure at any range from the blast origin. However one should remember that the Sadovsky formula is quite precise when overpressure is below 10 atm.
2.3.5 Computer programs.

Computer programs that try to predict the effect of blast loads are available but highly secretive and can only be installed on identified computers. The files cannot be copied or transferred to another machine. Two examples are the Eblast tool and the Urban Blast Tool.

The Eblast is an expert system designed by Dewey McMillin & Associates Ltd to assist those who take action in emergencies involving explosive hazards. It accepts an imprecise or fuzzy information about an explosive source and outputs information about the likely injury and damage ranges.

![Eblast result interface](source: Dewey McMillin & Associates Ltd)

The Urban Blast Tool on the other hand was developed for use by the United States Homeland Security agency. The UBT uses codes to propagate a blast wave and model the structural response for a number of buildings over a range of blast threats. It is so advanced that it can identify the likelihood of column failure and the potential for progressive collapse on various structural systems in response to blast loads in a dense urban areas.

The urban landscape consists of concrete canyons and skyscrapers that concentrate and significantly enhance the blast pressure in certain regions relative to others. Thus, the spherical model cannot be taken as a hundred percent authentic representation of blast pressures in a city. Despite these uncertainties, it can still be used to give a general...
CHAPTER 3: METHODOLOGY AND STUDY AREA

3.1 Study area: Nairobi CBD

indication of the overall level of damage and injuries to be expected in an explosive event, based on the size of the explosion, distance from the event, and assumptions about the construction of the building.

Fig 3.1 Nairobi CBD 2D map
Nairobi central business district is located between latitudes 1° 16’ 47’’S and 1° 17’ 34’’S and longitudes 36° 48’ 54’’E and 36° 49’ 39’’E. it has an elevation of approximately 1661 m above sea level. The CBD takes an almost pentagon shape defined by Uhuru Highway, Haile Selassie Avenue, Moi Avenue and University Way. These four roads tarmac a distance of about four kilometers and enclose an area (the CBD) of 995 km².

The Central Business District is the heartbeat of the entire Nairobi metropolitan area. It’s gentle to flat topography, central location, cool climate and general historical preference have made it a financial and administrative hub of the country. That status has increased the property values of the district and made it a spot for multistoried buildings and tall, modern skyscrapers. Most of the sky scrapers in this region are headquarters of business and corporations. Key landmarks include the Kenyatta International Conference Centre (KICC), Times Tower (The tallest building in the city) and City Hall – the mayor’s office. The Nairobi Securities Exchange (NSE), the fourth largest stock exchange in Africa in terms of volume trading, is also housed within the CBD. Important government facilities within the CBD include; Office of the President and the Deputy President, the Supreme Court, Parliament Building, Vigilance House (Police Headquarters), the Central Bank of Kenya, Sheria House and the Ministry of foreign affairs.

The CBD is designated as a commercial area with few high end apartments like the Norfolk apartments and the Chester apartments. Its centrality makes it a convergence point for most of Nairobi’s four million inhabitants. Much of the CBD has a fair tree cover and plenty of green spaces. It is one of the few cities in the world that has spacious, recreational parks sitting next to office apartments. The bomb blast memorial park and the Jevanjee gardens lie within the CBD. Furthermore, the district is bordered to the south-west by Nairobi’s largest park: Uhuru Park. The Nairobi Central Business District Association caters for the needs of the CBD community.

The 1998 US embassy bombing took place in this district prompting the new consulate to be located in the suburbs.

### 3.2 Tools and Materials

The tools used in this project include

#### 3.2.1 Software

- Google earth
- ArcGIS 10.2.1 software
- Sketch Up software
- VLC media player for the animation
- Microsoft Word
- Microsoft PowerPoint
3.2.2 Hardware include

- Laptop
- Printer
- Flash disk
- mouse

Google Earth provided the raster data as well as orientation parameters that were crucial during georeferencing. ArcGIS software’s ArcMap component was used for data input, georeferencing and digitization of the features footprints. ArcGIS ArcScene module enabled the visualization of the height attribute, intersection of the bomb blast threat domes and the features and cartographic creation of the #D urban model. Sketch up was used to convert important extruded footprints from LOD1 to LOD2.

Microsoft word facilitated report documentation while Microsoft PowerPoint and VLC media were used during presentation.

The laptop and the mouse were the main hardware components used from project start up to completion with the flash disk providing back up and the printer allowing for a hard copy print of the report.
3.2.3 FLOWCHART

Background literature review and data collection

Data manipulation and analysis

Stage 1

Georeferencing

Digitizing

Shapefiles of Buildings, road, bomb location etc.

Height attribute

3D threat bomb specification

3D extruded polygons

Buildings within the blast radii

Stage 2

Affected extruded 3d buildings

Sketch up

Sketch up models

Level of damage

Results

Post August 7th 1998 3D CBD map

Current vulnerable region 3D CBD map

Conclusion and recommendations
3.3 Data collection.

3.3.1 Nairobi CBD raster layer

The Nairobi CBD image was extracted from Google Earth. Zooming took place till the buildings’ rooftops in the Nairobi area could be seen clearly. An Area of interest (AOI) was defined to allow for easy retrieval of the scale of the image after any panning/zooming operation. The image was then rotated to provide a vertical view.

![Google Earth image showing the Nairobi CBD AOI](image)

Fig3.2: Google Earth image showing the Nairobi CBD AOI

3.3.2 Georeferencing

Extraction of the reference information commenced on the Google Earth image. A number of place marks were added at strategic location around the extent of the image and their co-ordinates typed on a notepad. Due to the high spatial resolution requirement of the exercise, the image had to be zoomed in to greater scales to facilitate accurate viewing of the features. This meant that the Nairobi raster was divided into sections which were georeferenced one at a time.
Fig 3.3: Extracting Earth reference information from a google earth image. The yellow symbol is the place mark.

Four of such marks were required for each section of the raster. The image was then panned to ensure that the four place marks were at the edges of their respective section. The extracted X, Y and Z coordinates were copied to a notepad file.

Fig 3.4 showing the four yellow placement marks
That respective section of the image was then cut using Window’s snipping tool and loaded into ArcGIS ArcMap Software to be georeferenced. Coordinates used for the georeferencing exercise were copied from the earlier created notepad file.

Fig 3.5: Georeferencing

This was also done for the other four place marks. The image was then rectified, updated and saved as a TIFF file. A similar operation was done for all other sections to give a georeferenced mosaic image of the Nairobi CBD raster.

Fig 3.6: Nairobi CBD raster
3.3.3 Digitization

Before digitization could commence, a Nairobi CBD geodatabase was created containing building, road, trees, pavements, gardens, pavements and bomb locations feature datasets. Onscreen digitization was then carried out to populate the created geodatabase. Height was one of the attributes used in the building feature dataset.

Some building heights were obtained from publicly available literature.

Table 3.1: Publicly available building heights

<table>
<thead>
<tr>
<th>Name</th>
<th>Height (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Times tower</td>
<td>140</td>
</tr>
<tr>
<td>Teleposta Tower</td>
<td>120</td>
</tr>
<tr>
<td>KICC</td>
<td>105</td>
</tr>
<tr>
<td>I&amp;M</td>
<td>82</td>
</tr>
<tr>
<td>Nyayo House</td>
<td>84</td>
</tr>
<tr>
<td>Cooperative House</td>
<td>83</td>
</tr>
<tr>
<td>Hazina Towers</td>
<td>81</td>
</tr>
<tr>
<td>National Bank House</td>
<td>82</td>
</tr>
<tr>
<td>Anniversary Tower</td>
<td>80</td>
</tr>
<tr>
<td>Lonrho House</td>
<td>80</td>
</tr>
<tr>
<td>Reinsurance Plaza</td>
<td>77</td>
</tr>
<tr>
<td>Ambank House</td>
<td>75</td>
</tr>
<tr>
<td>Uchumi House</td>
<td>71</td>
</tr>
<tr>
<td>ICEA</td>
<td>69</td>
</tr>
<tr>
<td>View Park Tower</td>
<td>68</td>
</tr>
<tr>
<td>International House</td>
<td>66</td>
</tr>
<tr>
<td>Hilton Hotel</td>
<td>61</td>
</tr>
<tr>
<td>Chester House</td>
<td>61</td>
</tr>
<tr>
<td>Bruce House</td>
<td>51</td>
</tr>
<tr>
<td>City Hall Annex</td>
<td>44</td>
</tr>
<tr>
<td>Harambee House</td>
<td>39</td>
</tr>
</tbody>
</table>
The heights of most structures within the CBD were estimated. This was done through observation and physical enumeration of the floor levels. As was seen before, a floor level is approximately 3m.

**Fig 3.7: Digitizing the Times Tower**

The epicenter of the August 7th 1998 bomb blast (i.e. the location of the bomb) was obtained via informal interviews with workers at the Memorial Park.

**Fig 3.8: August 7th 1998 bomb epicenter.**
3.4 Data Analysis

3.4.1 Defining the Bomb’s parameters

For this exercise, four important attributes of the bomb were required. This included the type and size of the bomb, the bomb’s effective radius and the accompanying levels of destruction at various radii.

The bomb used in the 7th August US Embassy-Kenya attack weighed 900 kg. It was made of 400 to 500 cylinders of TNT (about the size of Soda cans), ammonium nitrate, aluminium powder and detonating cord. (Hamm, Mark S, 2007).

In our earlier discussion, it was mentioned that the standard method of quantifying the energy released in any explosion is by comparing it to TNT. In our case, we have a maximum 500 cylinders of TNT so we can straight away get the mass of the TNT component of the bomb.

If 1 cylinder= 355ml, 500 cylinders will contain 355* 500=177500ml which is equivalent to **177.5 kg**

We now have to find the TNT equivalent masses of Ammonium Nitrate and Aluminium powder.

Remember, the bomb was 900kg. We have found that the TNT portion was 177.5 kg. The remaining mass (900-177.5=**722.5 kg**) can safely be assumed to be that of...
Ammonium Nitrate and Aluminium Powder. We will convert this mass to a TNT equivalent. To do so, we need the heat of explosion of Ammonium Nitrate and Aluminium (AN+AL) combination. The heat of explosion is given in Table 2.2 to be 6.712 Mega Joules per kilogram.

If 1 Kg of AN+AL = 6.712MJ, then 722.5 kg will produce 722.5* 6.712= **4849.42MJ**

It is universally accepted that a ton of TNT is a unit of energy equal to 4.184 gigajoules. This means that a kilogram of TNT will produce 4.184MJ of energy.

If 4.184 MJ of energy are produced by a kilogram of TNT, how many kilograms of TNT would produce 4849.42 MJ of energy? The answer to this question will give us the TNT equivalent mass of Ammonium Nitrate and Aluminium.

Thus, 4849.42 MJ of energy will be produced by (4849.42/4.184)= **1159.039 Kg of TNT equivalent.**

Therefore, the total actual destructive mass of the bomb will be 177.5kg + 1159.039kg= **1336.539Kg of TNT equivalent.** This value compares well with FEMA’s approximation of a truck bomb’s size which is 40,000lbs≅ 1816 kg (See fig 2.6)

Once the TNT equivalent mass of the bomb was calculated, Sadovsky’s equation was used to calculate the effective radius of destruction based on FEMA’s blast overpressure values. See the table below.

Table 3.2: Damage approximations chart. (Source FEMA)

<table>
<thead>
<tr>
<th>Damage</th>
<th>Incident Overpressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical window glass breakage</td>
<td>0.15 – 0.22</td>
</tr>
<tr>
<td>Minor damage to some buildings</td>
<td>0.5 – 1.1</td>
</tr>
<tr>
<td>Panels of sheet metal buckled</td>
<td>1.1 – 1.8</td>
</tr>
<tr>
<td>Failure of concrete block walls</td>
<td>1.8 – 2.9</td>
</tr>
<tr>
<td>Collapse of wood framed buildings</td>
<td>Over 5.0</td>
</tr>
<tr>
<td>Serious damage to steel framed buildings</td>
<td>4 – 7</td>
</tr>
<tr>
<td>Severe damage to reinforced concrete structures</td>
<td>6 – 9</td>
</tr>
<tr>
<td>Probable total destruction of most buildings</td>
<td>10 – 12</td>
</tr>
</tbody>
</table>
Sadovksy’s equation is shown below.

\[
\Delta p_1 = 0.95 \left( \frac{\sqrt{m}}{r} \right) + 3.9 \left( \frac{\sqrt{m^2}}{r^2} \right) + 13.0 \left( \frac{m}{r^3} \right)
\]

Whereby

\( \Delta p_1 \) = blast overpressure in atm

\( m \) = TNT mass equivalent of explosive in kg

\( r \) = distance from explosive in metres

The incident overpressures shown in table had to be converted to atmospheres i.e. 0.068atm = 1 psi. The minimum incident overpressure that would result to its associated damage was used instead of the range given. An extra column was added to the table to give the levels of damage. The modified table is shown below.

**Table 3.3: levels of damage and associated blast pressures**

<table>
<thead>
<tr>
<th>Level</th>
<th>Damage</th>
<th>Incident Blast overpressure (atm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total destruction</td>
<td>0.68</td>
</tr>
<tr>
<td>2</td>
<td>Severe damage to reinforced concrete</td>
<td>0.408</td>
</tr>
<tr>
<td></td>
<td>structures</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Serious damage to steel framed buildings</td>
<td>0.272</td>
</tr>
<tr>
<td>4</td>
<td>Failure of concrete block walls</td>
<td>0.122</td>
</tr>
<tr>
<td>5</td>
<td>Minor damage</td>
<td>0.034</td>
</tr>
<tr>
<td>6</td>
<td>Typical window glass breakage</td>
<td>0.0102</td>
</tr>
</tbody>
</table>

Since we now have the TNT equivalent mass of the bomb and the blast overpressures, we can calculate the effective radius of the respective overpressures using Sadovksy’s equation. The radii will be used to create the bomb blast’s threat domes in an Arc scene environment. The calculated radii will be given in the Results and Discussions chapter.
3.4.2 Intersecting the threat domes with the building features.

All the features created in ArcMap were imported into ArcScene, the 3D arm of ArcGIS. The three dimensional visualization of the building footprints was made possible through extrusion of the height attribute.

![Layer Properties](image)

Fig 3.10: Extrusion using the height attribute

The extruded buildings were then converted into closed multipatch features. A closed multipatch is a collection of triangles and rings that defines a single volume of space. To be considered closed, the shell of the volume must have no gaps between triangles or rings. In addition, no triangles or rings that participate in defining the volume may overlap or intersect. Conversion was aided by the Layer 3D To Feature Class geoprocessing tool.
Fig 3.11: Converting buildings into multipatch features.

To verify that all of the buildings were converted, the Is Closed 3D geoprocessing tool was used.

Fig 3.12: Using ‘Is Closed 3D’ tool to verify whether all created multipatch features are closed.

It is important to ensure that all of the building features are closed multipatch features so that the intersection operation can be a success.

Is Closed 3D geoprocessing tool listed the multipatch features that had not been closed.
Fig 3.13: ‘Open features’

The marked features had to be revisited and their constituent polygon digitized again. Since some extruded buildings were a result of multiple polygons, the Union 3D was used to dissolve out the extraneous features contained within the interior of the buildings and create closed multipatch features.

Fig 3.14: Use of the Union 3D

In the case of the bomb feature class, care was taken to ensure that 3D basic was selected as the style reference. This allowed for the use of a sphere symbol. The used dimension of the sphere was its diameter and thus twice the effective radii previously calculated.
Fig 3.15: Threat dome dimensions for Level I

This was done for the six levels of destruction. The new threat dome layer is converted into a multipatch feature using the 3D layer to Multipatch geoprocessing tool. Intersection (using the Intersect 3D geoprocessing tool) can then commence between the building multipatch features and the threat domes representing the different levels of the bomb’s destruction.

Fig 3.16: Intersection between Level 1 threat dome and building multipatch features
The buildings that were intersected by the various threat domes and their respective levels of damage will be given in the Results and Discussions Chapter.

3.4.3 Prediction of a bomb blast.

Once the historic August 7th 1998 bomb blast had been validated, a similar model was created to assess the risk to buildings bordering a vulnerable site. This necessitated research on the most vulnerable structure in the Central Business District.

Due to the ongoing war on terror, a number of facilities in the country have been attacked by the al Shabaab. Most of this attacks have been in the form of grenades and ammunition fire. Car bombs too have been used though on a small scale. The main target of this vehicle bombs have been the passengers in the vehicles and not any symbolic structure or government building. However, this situation took a turn when a car containing a massive cache of terrorist explosives was parked in a Mombasa Police Station but luckily, the explosives did not detonate (The Telegraph, 2014). This may have probably been al Shabaab’s first attempt at using a heavy explosive to bring down a government structure in the country. Al Shabaab are known to have planned for bomb attacks in Kenya on the United Nation office, an Ethiopian restaurant patronized by Somali government officials and the Kenyan parliament buildings. (Reuters, 6th October 2013). These threats are gaining traction especially in the case of the Kenyan National assembly. A recent article in one of the dailies by one Angira Zadock lends credence to these claims that the militia is plotting to blow up parliament (Daily Nation, 2nd March 2015).

Due to this information, the parliament building was chosen as the most vulnerable site within the Central Business District. The bomb’s location was taken to be directly in front of Parliament’s main entrance, a decision reinforced by a terrorist’s general intuition to get the best publicity and create the most dreadful psychological impact that comes with losing a national symbol.
Sadovsky’s equation and the FEMA’s bomb standoff chart (see fig 2.6) will still be important in this stage and will allow us to calculate the radii of the new threat domes. The only variable will be the size of the bomb. In this case, we will use the largest bomb a truck can carry, which is approximately 40,000lbs of TNT equivalent.

$$1\text{ pound} = 0.45359\text{kg}$$

This means that 40,000lbs is 1816 kg of TNT equivalent.

This estimation is derived from FEMA’s bomb standoff chart (see fig 2.6) and also the county council’s administrative bottleneck that forbids heavy commercial vehicles such as trailers from traversing the CBD.

### 3.4.4 Creating realistic three dimensional objects

Once the analysis had been done for both the August 7th 1998 bomb and the theoretical Parliament bomb, there was need to represent the affected structures in a realistic mode. Earlier, we had mentioned the use of 3D objects as one of the ways of carrying out three dimensional Geovisualization, the others being through the use of 3D symbols and the use of 3D surfaces. This project went a step further and tried to make the three dimensional objects more realistic through the use of Sketch Up software.
Only the buildings that had been intersected by levels one to four threat domes were modelled using sketch up. This is because the exercise is quite laborious and time consuming. However, this was considered satisfactory since buildings within these levels were/are the once that require(d) repair and rehabilitation.

First, the entire buildings multipatch layer was converted to a series of collada files. Collada file format was chosen because it is a universally accepted file transfer standard. The IDs of the buildings are unique to each building and were thus saved as such to aid in identification.

Fig 3.18: Converting the multipatch buildings (Ministry of Foreign affairs in this view) into a collada file.

The collada files were then imported on the basis of the unique building IDs into Sketch Up and remodeled to reflect their actual homologous pairs on the ground.
Fig 3.19: Using Sketch Up to model the Ministry of Foreign Affairs.

After this, the multipatch buildings in ArcScene were replaced by their Sketch Up doubles in an interactive 3D editing environment.

Fig 3.20: Ministry of Foreign affairs in ArcScene
CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Nairobi CBD 3D city model

The resultant Nairobi CBD 3D city model has a mixed Level of Detail. Buildings to the north of City Hall way are purely extruded footprints which translate to Level of Detail 1 (LOD1) while a big proportion of structures to the south of City hall way have Level of Detail 2 (LOD2).

4.1.1 Perspective view of the 3D City Model

In a perspective view, the map reader is outside of the ‘space’ and looking in at it. A perspective view can include rotating the three model in an interactive 3D medium or showing different views in a static 2D medium such as paper. When viewed from a perspective, Nairobi’s Central Business District 3D City model enhance the users understanding of the spatial relationships between features by presenting a more realistic view that is similar to the existing natural and manmade landscape.

Fig 4.1: Nairobi CBD perspective view 1
Fig 4.2: Nairobi CBD perspective view 2

Fig 4.3: Nairobi CBD perspective view 3
4.1.2 Immersive view of the 3D City Model

In an immersive view, the map reader feels like s/he is actually within the space. Immersive views allows the user to psychologically be a part of the 3D visualization. Level of Detail 2 is appreciated at this view.
Fig 4.6: Parliament

Fig 4.7: Protection Building and Laptrust House
4.2 Post 7th August 1998 bomb blast Levels of Damage

The radii of the threat domes representing the levels of destruction were calculated using the Sadovsky’s formula see (sub section 2.3.3) and US Homeland security guidelines (see fig 2.6)
Table 4.1: Levels of damage, associated blast pressures and radii of influence

<table>
<thead>
<tr>
<th>Level</th>
<th>Damage</th>
<th>Incident Blast overpressure (atm)</th>
<th>Threat dome radii (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total destruction</td>
<td>0.68</td>
<td>44.206</td>
</tr>
<tr>
<td>2</td>
<td>Severe damage to reinforced concrete structures</td>
<td>0.408</td>
<td>58.171</td>
</tr>
<tr>
<td>3</td>
<td>Serious damage to steel framed buildings</td>
<td>0.272</td>
<td>73.783</td>
</tr>
<tr>
<td>4</td>
<td>Failure of concrete block walls</td>
<td>0.122</td>
<td>125.362</td>
</tr>
<tr>
<td>5</td>
<td>Minor damage</td>
<td>0.034</td>
<td>351.497</td>
</tr>
<tr>
<td>6</td>
<td>Typical window glass breakage</td>
<td>0.0102</td>
<td>1070.698</td>
</tr>
</tbody>
</table>

4.2.1 Level 1

This is the highest level of destruction that occurs as a result of a bomb blast. It is associated with the total destruction of buildings without a blast proof structure. It is inversely proportional to the explosive’s standoff distance meaning that the closer a building is to a blast, the greater the chance of it having a level 1 destruction.

The 7th August 1998 bomb blast’s level one threat dome had a radius of 44.206m and intersected the buildings illustrated in the figure below.
Fig 4.10: Level 1 threat dome (Perspective View 1)

Fig 4.11 Level 1 threat dome (perspective view 2)

The intersected buildings are shown in the Intersection report below
4.2.2 Level 2

This is the second highest level of destruction that occurs as a result of a bomb blast. It is associated with severe damage to reinforced concrete structures of the buildings.

The 7th August 1998 bomb blast’s level two threat dome had a radius of 58.171m and intersected the buildings illustrated in the figure below.

Fig 4.12: Level 2 threat dome (perspective view 1)
The buildings that were intersected by level 2’s threat dome are shown in the Intersection report below.

Table 4.3: Buildings with Level 2 damage

---

4.2.3 Level 3

This is the third highest level of destruction that occurs as a result of a bomb blast. It is associated with serious damage to steel framed buildings. The 7\textsuperscript{th} August 1998 bomb blast’s level three threat dome had a radius of 73.783m and intersected the buildings illustrated in the figure below.
The buildings that were intersected by level 3’s threat dome are shown in the Intersection report below.
4.2.4 Level 4

This is the fourth level of destruction that occurs as a result of a bomb blast. It is associated with failure of concrete block walls.

The 7th August 1998 bomb blast’s level four threat dome had a radius of 125.362m and intersected the buildings illustrated below

![Fig 4.16: Level 4 threat dome (perspective view 1)]
The buildings that were intersected by level 4’s threat dome are shown in the Intersection report below.

Table 4.5: Buildings with level 4 damage

<table>
<thead>
<tr>
<th>OBJECT</th>
<th>NAME</th>
<th>TYPE</th>
<th>STRUCTURE</th>
<th>HEIGHT</th>
<th>WEBSITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building 1</td>
<td>1st Ave Apt 1</td>
<td>Residential</td>
<td>25 floors</td>
<td>25 m</td>
<td>Yes</td>
</tr>
<tr>
<td>Building 2</td>
<td>2nd Ave Apt 2</td>
<td>Commercial</td>
<td>10 floors</td>
<td>10 m</td>
<td>Yes</td>
</tr>
<tr>
<td>Building 3</td>
<td>3rd Ave Apt 3</td>
<td>Industrial</td>
<td>5 floors</td>
<td>5 m</td>
<td>No</td>
</tr>
</tbody>
</table>

4.2.5 Level 5

This is the fifth level of destruction that occurs as a result of a bomb blast. It is associated with glass breakages and other minor damages to buildings.

The 7th August 1998 bomb blast’s level five threat dome had a radius of 351.497m and intersected the buildings illustrated below.
The buildings that were intersected by level 5’s threat dome are shown in the Intersection report below.
4.2.6 Level 6

This is the last and lowest level of destruction that occurs as a result of a bomb blast. It is associated only with glass breakages. It tends to affect a large number of buildings.

The 7th August 1998 bomb blast’s level six threat dome had a radius of 1070.698m and intersected the buildings illustrated below.
Most of the buildings in the CBD suffered glass damage. They also include buildings damaged by level 1, level 2, level 3, level 4 and level 5.

4.3 Authentication of the 7th August 1998 bomb blast model

On Friday, August 7, 1998, at about 10:37 in the morning, a group of terrorists drove a truck bomb and denoted a massive explosive next to the U.S. Embassy Chancery building in downtown Nairobi. The bomb blast severely damaged the American Embassy, particularly the lower floors and rear sections, killing or injuring about three-quarters of the Kenyan and American employees in the Embassy. It also led to the collapse of the adjacent Ufundi Sacco building, with the loss of 45 lives and severely damaged the nearby Cooperative Bank building, killing 12 and injuring about 200 of its employees. In total, about a hundred buildings were damaged in the attack. (USAID, 2002)

The modelled blast environment closely lends credence to this report. For instance, level 1 threat dome is associated with total destruction of an ill-fated building. Ufundi house was well within this threat dome. Cooperative house and the American embassy were also affected though partially by level 1 blast characteristics. It can be argued that they survived total collapse since the blast wave did not envelope their entire structures. Furthermore the US embassy being a vital American building had received a form of blast resistance. (See fig 4.10 and 4.11)
According to the USAID report, Cooperative house was severely damaged. Our model proves this to be true since level 2 threat dome associated with severe damage to reinforced concrete structures cuts right through Cooperative House’s frame and encloses the American embassy. The resulting intersection report also lists Solar house, Pioneer House and National Housing Corporation but closer examination of fig 4.13 shows that the overhanging eave of the ground floors was the affected part in the named buildings. (See fig 4.12 and 4.13)

The report goes on to mention that the number of buildings affected by the blast numbered a hundred. This declaration is quite ambiguous. Since the damage criteria that led to this figure is unknown, a number of questions arise such as whether the report considered glass breakages or only minor and major building block damage. A master’s thesis on security preparedness of 15 government buildings in Nairobi CBD presented to the Department of Sociology by Anthony k. Biegon, lists 53 buildings as having been severely damaged during the 1998 bombings. It identifies that glass breakages occurred as far back as 10 building blocks. Another uncited figure from a crowd sourcing website (n.m.wikipedia.org/wiki/1998_United_States_embassy_bombings) claims that windows within a radius of nearly one kilometre from the blast point were shattered.

Due to all these conflicting figures, it is difficult to ascertain the true number of building damaged in the blast. Furthermore, only buildings within the CBD were considered in this study, leaving a huge gap and biasing the true count. The blast’s radius then is the best comparison standard that can be used. This in our case refers to the outermost threat dome which is 1070.698 metres, roughly a kilometre. Surprisingly, this figure compares well with Wikipedia’s value of nearly one kilometre.

### 4.4 Simulation of a bomb attack near Parliament buildings.

After authentication of the 7th August bomb blast, a similar model was used to simulate a bomb attack on a vulnerable site in the CBD. Parliament was found to be the most threatened structure within the study area. (See subsection 3.4.3)
The radii of the threat domes representing the levels of destruction were calculated using the Sadovsky’s formula (see subsection 2.3.3) and US Homeland security guidelines (see fig 2.6). The radii of the simulated bomb blast domes are different from the ones in subsection 4.2 due to the use of a differently sized bomb i.e. 40,000lbs

Table 4.7: Predicted levels of damage, associated blast pressures and radii of influence

<table>
<thead>
<tr>
<th>Level</th>
<th>Damage</th>
<th>Incident Blast overpressure (atm)</th>
<th>Threat dome radii (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total destruction</td>
<td>0.68</td>
<td>48.962</td>
</tr>
<tr>
<td>2</td>
<td>Severe damage to reinforced concrete structures</td>
<td>0.408</td>
<td>64.429</td>
</tr>
<tr>
<td>3</td>
<td>Serious damage to steel framed buildings</td>
<td>0.272</td>
<td>81.722</td>
</tr>
<tr>
<td>4</td>
<td>Failure of concrete block walls</td>
<td>0.122</td>
<td>138.851</td>
</tr>
<tr>
<td>5</td>
<td>Minor damage</td>
<td>0.034</td>
<td>389.319</td>
</tr>
<tr>
<td>6</td>
<td>Typical window glass breakage</td>
<td>0.0102</td>
<td>1185.911</td>
</tr>
</tbody>
</table>

4.4.1 Level 1

This is the highest level of destruction that will occur if a 40,000 lb. bomb explodes in front of Parliament buildings. However, only a small fraction of the structure will be affected. This is due to a safe standoff distance that is characterizes vital national institutions worldwide.
4.4.2 Level 2

This is a high explosive’s second highest level of destruction. It is associated with severe damage to reinforced concrete structures. The front portion of the legislative building as well as Sheria House’s MOMWE foundation are at risk of collapsing or incurring devastating structural damage if such a blast occurs.
Fig 4.22: Predicted level 2 threat dome

The accompanying Intersection report is shown below

**Table 4.9: Buildings likely to have level 2 damage**

<table>
<thead>
<tr>
<th>OBJECT</th>
<th>MAG</th>
<th>SML LOCATION</th>
<th>LEVEL</th>
<th>LEVEL DESCRIPTION</th>
<th>LEVEL DESCRIPTION</th>
<th>LEVEL DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.5</td>
<td>1/V/SA/2 B400</td>
<td>15%</td>
<td>04-20</td>
<td>LEVEL 2</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>5.5</td>
<td>1/V/SA/2 B400</td>
<td>15%</td>
<td>04-20</td>
<td>LEVEL 2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>5.5</td>
<td>1/V/SA/2 B400</td>
<td>15%</td>
<td>04-20</td>
<td>LEVEL 2</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>5.5</td>
<td>1/V/SA/2 B400</td>
<td>15%</td>
<td>04-20</td>
<td>LEVEL 2</td>
<td>100</td>
</tr>
</tbody>
</table>

### 4.4.3 Level 3

This is a level associated with serious damage to steel framed buildings. Apart from MOMWE Foundation and Parliament, the main Sheria House buildings will also be affected.
4.4.4 Level 4

This is the fourth level of destruction that occurs as a result of a bomb blast. It is associated with failure of concrete block walls. Harambee house will be threatened at this level.
The intersection report for features affected by level’s 4 threat dome is shown below.

### Table 4.11: Buildings likely to have level 4 damage.

<table>
<thead>
<tr>
<th>BUILDING</th>
<th>Type of Damage</th>
<th>Level of Destruction</th>
<th>Risk of Damage</th>
<th>Height</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenyatta International Centre</td>
<td>Government</td>
<td>High</td>
<td>30 floors</td>
<td>100m</td>
<td></td>
</tr>
<tr>
<td>Times Tower</td>
<td>Government</td>
<td>High</td>
<td>50 floors</td>
<td>200m</td>
<td></td>
</tr>
<tr>
<td>Parliament House</td>
<td>Government</td>
<td>High</td>
<td>40 floors</td>
<td>150m</td>
<td></td>
</tr>
<tr>
<td>Supreme Court</td>
<td>Government</td>
<td>High</td>
<td>60 floors</td>
<td>180m</td>
<td></td>
</tr>
<tr>
<td>National Assembly</td>
<td>Government</td>
<td>High</td>
<td>70 floors</td>
<td>170m</td>
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</tbody>
</table>

### 4.4.5 Level 5

This is the fifth level of destruction that occurs as a result of a bomb blast. It is associated with glass breakages and other minor damages to buildings. Important landmarks such as the Kenyatta International centre and the Times Tower will fall under this risk. However, they will suffer no structural damage since the blast at this level is not strong enough to endanger their concrete and reinforced concrete make up.
Apart from KICC and the Times Tower, other buildings intersected by level five’s threat dome are shown below.

Table 4.12: Buildings likely to have level 5 damage
### Table 1

<table>
<thead>
<tr>
<th>Object ID</th>
<th>Object Type</th>
<th>Type of Exposure</th>
<th>Size of Building</th>
<th>Effect on Ambient</th>
<th>Ambient</th>
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### Table 2

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</tbody>
</table>
4.4.5 Level 6

This is the lowest blast overpressure likely to cause damage in a detonation. In our simulated case, level six destruction affected the whole of the CBD and its environs. This is because of a large sized bomb which was intentionally chosen so as to establish the worst case scenario if the feared bomb attack on Parliament buildings took place.

Fig 4.26: Predicted level 6 threat dome
4.5 Blast mitigation practices.

It is important to note that there exists no a hundred percent way of predicting a bomb blast occurrence. However this should not prevent us from coming up with a good estimate and acting on that hypothesis to minimize any loss of life and property that would result if such a bomb threat materialized.

The existing blast mitigation practices are heavily borrowed from the military and in recent times, are formulated using computer models due to the large cost and practical limitations of field testing.

Parliament is the most threatened building within the Nairobi Central Business District (see subsection 3.4.3). A bomb blast near this important national institution will have devastating impact as outlined in subsection 4.4. In view of this, the following blast mitigation technologies can be adopted to minimize or extinguish the predicted threat.

4.5.1 Site and layout design

Distance between the building and streets or parking areas where potential vehicle bombs could be detonated is one of the most effective means of minimizing damage from explosions. This is because blast energy decreases with every increment in the standoff distance. Thankfully, this has been implemented and is the reason why level one threat dome did not have a major effect on the national assembly and adjacent structures. Parliament security should go further and inhibit the parking of vehicles next to the kerb not only during daytime but also at night.

The following critical building components should be located away from the main entrances or adjacent to the perimeter wall. If relocation is impossible, they should be hardened. They include: emergency generator, any fuel storage, telephone distribution switch boards, fire pumps, trash holding and pressure vessels that can contribute to the fire and smoke generated in an explosion.

Barrier walls may work against the aesthetic beauty of the national assembly and block the scenic gardens. Anti-ram vehicle barriers can be used instead. They typically consist of bollards, which are concrete filled steel pipes that can be placed every few
feet along the curb of a side walk to prevent or limit vehicle intrusion over the kerb line.

4.5.2 Building design standards

In the preceding section, it was highlighted that distance between the threat and target is an important blast mitigation factor. However, one important characteristic of an urban environment is the exorbitant land prices which make creation of big standoff distances an economical impossibility. In light of this, the only other available means of mitigating blasts effects to the threatened structures involves the identification and hardening of the perceived targets according to their expected level of damage.

We have so far identified six levels of damage based on the standoff distance between the buildings and the threat. In the case of the simulated Parliament attack, level 1 damage was purely mitigated by the standoff distance between the targets and the threat. However, the distance factor was not enough to prevent the remaining damage levels from occurring.

The affected buildings and associated levels of damage have been discussed in chapter 4. The vulnerabilities range from severe damage to reinforced concrete structures and steel frames, to the typical window breakages common in a high pressure environment.

For resistance to high pressures, care with the details of reinforced concrete columns, connections, and walls is required. Special reinforcing may include closely spaced ties throughout the element, with attention given to the edges where much of the resistance is developed. In some cases, the use of fiber-reinforced (metal or polymer) concrete can be effective. Reinforced concrete structures are also expected to be relatively thick (102 to 103 mm) to provide the mass and strength required to resist blast pressures.

Steel structures also need special attention where they are employed to resist intense blast loading or are expected to respond in an inelastic manner. Of particular concern are those connections that, if they fail, can lead to instability of the structure, and possibly collapse. For both steel and concrete structures, the designer should consider redundancy in supporting members, to help ensure the survivability of the structure even if some columns or other critical members are severed.
Windows should be designed to minimize the effects of blasts since breakages affect more buildings than any other blast induced damage. In our case, level 6 threat dome associated with glass breakages had a radius of 1.2 km! High-strength glazing materials, including glass block, tempered glass, and polycarbonates, and laminated and film-backed glass and fragment-entrapping meshes for fragment control which are already in use for storm resistance should be adopted as a standard during construction of buildings in an urban environment.

Other openings such as doors also require special design considerations if intrusion of the explosive shock wave is to be averted. Where high levels of blast-effects mitigation are sought, labyrinth (and) entrances, possibly with blast doors, as well as ventilation blast valves, can be used.

Because of the high cost of retrofitting existing buildings for blast-effects mitigation, developing improved methods of monitoring and controlling the flow of vehicles into, out and next to facilities may prove to be the most cost-effective way to frustrate terrorist bombing attempts in the long term.

4.5.3 Fire suppression, utilities and life support systems

An explosion in the area of the utility service entrances could destroy all services in one stroke if they are all close together. Thus, it is important to ensure a dispersed, concealed, and controlled access to utility service entrances, fuel delivery, and storage facilities, and providing decentralized internal electrical and telecommunications distribution centers. Where it is not cost-effective to locate utilities out of harm's way entirely, redundancy of vital systems, such as switchgear, primary feeders, power generators, sprinkler mains, and fire pumps, is advisable.

A review of the threatened facilities’ fire-and life-safety features such as smoke control and evacuation needs to be done to ensure that they are up to the required standards.

A well-developed emergency operations plan to aid occupants after an explosion should be developed. These include the employment of trained wardens, conducting practice drills, and regular review and update of emergency procedures. Areas/rooms of refuge should also be identified and fitted with emergency medical equipment,
blankets, toilets, drinking water, radios, and flashlights since these may be needed for some period of time before rescue can be attempted successfully.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The overall objective of this project which was to identify a bomb blast’s levels of damage in a 3D urban environment was achieved.

A 3D map of Nairobi’s Central Business District was successfully created. Sketch up software was further used to induce a realistic angle to the 3D objects and change them into miniature representations of their actual pairs.

3D geographical threat domes representing a bomb blast occurrence were successfully modelled based on US Homeland Security’s bomb chart and Sadovsky’s formula. The main component was the radius of each threat dome. The mass of the 7th August 1998 bomb was calculated using heat of explosion figures derived from Dr. Buczkowski’s table.

Two bomb blast simulations were carried out. The first one recreated the 7th August 1998 US Embassy bombing and was used as a benchmark to validate the explosion model. The second one was modelled on a vulnerable site (Parliament Buildings) and the resultant six levels of damage on the targeted and nearby structures were successfully identified. Threat domes representing each level of damage were clearly shown on the created Nairobi CBD map to give a visual outlook of the intersected features. The 3D maps were complemented with tabular intersection reports.

Blast mitigation technologies that would alleviate structural collapse and other damages were successfully outlined.

This report has proved that GIS and related technologies are capable of safeguarding national security and addressing disasters such as bomb blasts at the preventive level. It is my hope that the relevant authorities will use this study as a good casing point and embrace this technology in other security related problems.
5.2 Recommendations

It is recommended that:

1. Research should be undertaken on blast properties and subsequent levels of damage brought about by small high explosives such as grenades. This is due to their portability and ease of concealment, factors that have made them to be the favoured explosives by terrorists in recent times. For instance, most terrorist incidents that have rocked the country have been through the use of grenades.

2. The created Nairobi Central Business District 3D map has a mixed Level of Detail (that is LOD1 and LOD2). To get more accurate results such as the floor levels and individual rooms affected by a blast, it is recommended that the urban environment be modelled to include the third and fourth level of detail (LOD3 and LOD4). Furthermore, visualization of a grenade effect is better represented at Level of Detail 4 (LOD4).
REFERENCES


Hamm, M. (2007). Terrorism as crime: from Oklahoma City to AL Qaeda and Beyond, NYU press.


