UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

TITLE: DEVELOPMENT OF A 3D INDOOR MODEL FOR MANAGEMENT OF EMERGENCY EVACUATION IN PUBLIC BUILDINGS.
CASE STUDY OF ARDHI HOUSE – NAIROBI.

BY

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F56/6815/2017

Research Project Submitted in Partial Fulfillment of the requirement for the degree of Master of Science in Geographic Information Systems in the Department of Geospatial and Space Technology of the University of Nairobi

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DEDICATION

To a safer tomorrow for all of us.

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ABSTRACT

Buildings have become a significant subject of recent disasters, either of natural or anthropogenic causes, resulting in massive casualties and damages in Kenya and almost everywhere else in the world. In the January 2019 travel advisory by the UK government, public buildings have been pointed out to be soft targets as a result of poor disaster preparedness and high human traffic.

Emergency evacuation in buildings is particularly challenging because of the complexity of structures, poor situational awareness and presence of other hazards like gas leaks and falling structures. Indoor navigation is also much slower due to slow walking speed, the uncertainty of routes, blockages and numerous dead ends.

The project aimed to design and develop a 3D indoor model incorporating mission-critical information for the management of indoor emergency rescue. The case study of this project was Third Floor, Wing C of Ardhi House. Indoor point cloud and panoramas of the observation area were obtained using Matterport Pro2 Lite 3D Camera MC250. Post-processing of the collected data was carried out through the Matterport cloud service using the Unity Engine plugin. The captured raw data was collected as a point cloud, depth data and panoramic images from the camera.

The project identified critical datasets to include indoor building data, dynamic and semantic building information and outdoor emergency information. These datasets were then incorporated into the model. The resulting 3D model was then enhanced to obtain a navigable 3D web scene augmented with mission-critical data accessible via a web browser. The project evaluation was then undertaken by querying for the mission-critical data, navigation and orientation.

The project's deliverables were limited especially by the short time available to undertake the project, high cost of data collection, limited functionality of the Matterport Workshop and the inefficiencies of the camera such as heating up and alignment errors.

The developed model was noted to be a step forward in availing critical information to rescue teams and victims during disasters and greatly improves situational awareness. The model achieved high accuracy in space representation, the camera was efficient in data collection and processing and the model was effective in information dissemination. The model could be improved to include all parts of buildings, include search and navigation functionalities and simulation of building collapse, fire and flood. The model may also be incorporated in other fields like cadastral mapping, urban planning, tourism, facility management and real estate valuation.

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UK:	United Kingdom
CCTV:	Closed Circuit Television
3D:	Three Dimension
2D:	Two Dimension
GIS:	Geographic Information System
CAD:	Computer Aided Design
CGA:	Computer Generated Architecture
ESRI:	Environmental Systems Research Institute
RGB-D:	Red, Green, Blue & Depth
PNG:	Portable Network Graphics
GNSS:	Global Navigation Satellite System
IMS:	Inertial Measurement System
SLAM:	Simultaneous Location and Mapping
VIP:	Very Important Person
GB:	Gigabyte
RAM:	Random Access Memory
ROM:	Read Only Memory
SSAO:	Screen Space Ambient Occlusion
CMOS:	Complementary Metal Oxide Semiconductor
HDR:	High Dynamic Range
Jpg:	Joint Photographic Expert Group
MP:	Megapixel
VR:	Virtual Reality
OLED:	Organic Light-Emitting Diode
QR:	Quick Release
4K:	Four times 1080 pixels
WebGL:	Web Graphics Library
MB:	Megabytes
MBPS:	Megabytes Per Second

1. INTRODUCTION

1.1 Background of the Study

Buildings have become a significant subject of recent disasters resulting in vast amounts of casualty and damage costs for both public and private individuals all over the world. These disasters either emanated from natural causes such as earthquakes, floods, cyclones, tornadoes, volcanic eruptions; or anthropogenic causes such as terrorism, structural failures and fire breakout (Hashemi, 2017). In the recent past, Kenya has had its fair share of crises arising from human causes especially acts of terror. In the January 2019 travel advisory by the UK government, public buildings were pointed out to be easy targets for acts of terror (GOV.UK, 2019).

In the past five years alone, almost 300 lives have been lost and scores injured in three major building attacks including Westgate Mall siege in September 2013, Garissa University College attack in 2015 and DusitD2 Hotel attack in January 2019 (The Standard, 2019). Fires have also gutted down several buildings leading to loss of lives and destruction of property, especially in schools. The worst fire incidences include Bombolulu Girls Secondary School in 1998, Nyeri High School in 1999, Kyanguli Secondary School in 2001 and Moi Girls in 2007 (The Standard 2016). Other disasters involving buildings also include numerous building collapses especially in Nairobi, the latest case being the Huruma Estate building which left four people dead and millions of shillings lost in property's worth.

Emergency evacuation in buildings is particularly challenging because of the complexity of structures, availability of underground facilities, high-rise structures and other imminent hazards such as gas explosions, electrical failures and the risk of falling debris. Much information on the properties of the building is usually unavailable to the rescue team thus reducing their effectiveness and putting their lives in danger too. Indoor navigation is also much slower due to slow walking speed, stairs and ramps, the uncertainty of routes, blockages and closed doors and distribution of smoke (Giljanovi, 2015).

It is important to note that the chances of saving victims in buildings under attack depend on the speed of the primary search. The unavailability of concise information on accurate indoor floor maps indicating the number of floors, entrance and exits, panic rooms, remote access to CCTV cameras, knowledge on the number of people in the building and the fastest route out of the building make it difficult for the search and rescue team resulting in more casualties (Xu, 2015).

In the recent attacks experienced in the country, access to the blueprints of the buildings quick enough was an enormous challenge. Where the 2D maps were available, the evacuation plan had to be rapidly developed at the site of the attack. Understanding such maps are often problematic under such immense pressure and one can quickly get disoriented and trapped in the building (Gangaputra, 2017). Also, the victims are often unable to exit the building especially if they are visitors and sometimes ending up cornered in dead ends.

Dynamic visualisation of premises improves situational awareness and eases property description to first responders who are not familiar with the building (Makdoom, 2015). This project has therefore developed a web-based 3D indoor model of the Third Floor Wing C of Ardhi House to assist in the management of emergency evacuation, especially during a terror attack. The model incorporates information on floor plans, staircases, gathering points, building material, the location of emergency facilities such as firefighting equipment, hazardous materials as well as information on occupancy. The 3D model is web-based hosted on a dedicated portal and made available to the public.

1.2 Problem Statement

In most terror attacks that have occurred in Kenya, it takes quite long for the security officers to neutralise the attack, the longest being the Westgate Mall siege which lasted four days. Many reasons leading to this delay have been cited by various reports, one of them being poor coordination among the rescue teams. In most cases, the building plans, which are vital in planning the rescue mission, were either inaccessible or unavailable leading to the rescuers carrying out the operation without proper situational awareness.

For an emergency rescue team to succeed during any emergency evacuation within a building, the establishment and utilisation of situational awareness cannot be overemphasised. The knowledge of the optimal routes to get to the victims, if provided before the rescuers enter the building, greatly improves their success rate. The aim of this project was therefore to develop a 3D indoor model augmented for emergency rescue by enhancing localisation, visual cognition and orientation of the indoor environment both for the victims and rescuers.

1.3 Research Objectives

The overall objective of this project was to design and develop a 3D indoor model for management of emergency evacuation from Third Floor, Wing C of Ardhi House in Nairobi.

The specific objectives are as noted below:

i. Identify specific types of information regarding the space and features inside a public building that is required by the first responders and victims to facilitate efficient and effective evacuation during an emergency.

ii. Develop a photorealistic 3D indoor model for Ardhi House, 3rd Floor Wing C and incorporate the identified mission-critical information.

iii. Identify potential building hazards which may complicate emergency evacuation and incorporate them into the model.

iv. Query the model to assess its response to the information needs of the first responders and victims.

1.4 Justification for the Study

Buildings have become major sites of disasters ranging from collapsed buildings to terror attacks which have claimed countless lives all over the world. Availability of a web-based 3D model of buildings with mission-critical data requirements promises situational awareness of both the victims and rescuers. Situational awareness ensures that the first responders can enter the building soon enough without fear of the looming hazard hence improving the success of the rescue mission (Giljanovi, 2015).

Research has also proved that 3D indoor maps are better understood than 2D building plans especially in delicate missions where situational awareness is critical (Giljanovi, 2015). Further, the 2D plans, on many occasions have been inaccessible at the time of the disaster. The project, therefore, provides reliable and accurate information on buildings that will inform the formulation and coordination or rescue missions. 3D indoor plans can also be used in other property administration functions such as tax assessment, valuation validation, planning regulations enforcement, property letting, virtual tour and robotics (Chang et al., 2018).

1.5 Scope of Work

The focus of this research is on the provision of the mission-critical information for situational awareness improvement for management of indoor evacuation during a crisis. An indoor crisis can include a wide range of events such as fires, chemical spills, earthquakes, gas leakages, terrorist attacks, etc. Although modelling the indoors spatially can increase indoor situational awareness for all such incidents and assist decision makers to have a better view of the incident scene, and since the research is unable to encompass the entire indoor disasters, this research is mostly focused on terrorist attacks which have become rampant in our country and necessitate situational awareness and require swift action.

Although the 3D model can play a significant role in increasing indoor situational awareness and improving the knowledge of indoor areas even without localisation systems due to the creation of a 3D conceptualised model, indoor pathfinding and navigation are reliant on an accurate indoor positioning system. However, the localisation and pathfinding techniques are beyond the scope of this study.

The main aim of the project is to model the indoors geometrically and semantically to improve the success of search and rescue missions by aiding the mission planning. Dynamic factors which affect the ease of accessibility of areas such as fire dynamics, the collapse of sections of buildings, and smoke movement are beyond the scope of this project.

Finally, the project focuses on public buildings because most security warnings have always cited a public building as a soft target. Public buildings are also poorly managed, poorly secured and has very high human traffic at any given time. These conditions create an easy target for acts of terror.

The project was, therefore, carried out on the third floor, Wing C of Ardhi House which is a public building hosting the Ministry of Lands and Physical Planning, Valuation Directorate. The choice of Third Floor Wing C was informed by the relatively lower human traffic, ease of access and simplicity in design hence, developing the 3D model would take a relatively shorter time and lower the cost of undertaking the project.

1.6 Organisation of the Project Report

The project report is organized into five chapters that are related to the general flow of ideas throughout the research project. Chapter 1 is primarily introductory and captures the following; the introduction to the study, problem statement, objectives, scope of the study, organization of the study and definition of terms. In Chapter 2, review of the relevant literary work that had been undertaken in the discipline is done. The literature review discusses the enabling technology for the actualization of the project and also provides secondary data for the project. Finally, a summary and conclusion for the chapter mark its end. Chapter 3 is on the material and methods employed in realizing the objectives of the project. It provides background information on the case study. This chapter also explains the requirements analysis, the apparatus to be used, the data acquisition process, data processing, the identified mission-critical information and the procedure of querying the model. In Chapter 4, the results of the collected data are discussed guided by the specific objectives of the project. Chapter 5 is about conclusions and recommendations. It provides the conclusion of the project, the limitations of the project and recommendation of future work on the project for it to be improved.

2. LITERATURE REVIEW

2.1 Introduction

The rapid growth of GIS and supporting computing technologies have redefined space to include both the outdoor environments and indoor environments (Giljanovi, 2015). Three-dimensional representations of the indoor areas provide better conceptualisation and perception for humans who are stereoscopic and can assist in a more organised decision making, particularly in an unfamiliar indoor environment (Tashakkori, 2017). Therefore, 3D geospatial data are being applied more in many areas such as city planning, cadaster information management, emergency response, evacuation, facilities and utility management, virtual reality, entertainment, et cetera.

According to (Yang and King, 2009), a 3D indoor system that can be utilised for search and rescue missions must be based on a very detailed and accurate building model that incorporates building geometric and semantic elements, and a navigable model. The system should be able to facilitate situational awareness, decision-making procedures and route planning.

In developing such a system, it is crucial to identify and provide mission-critical information required by the rescuers and the victims during emergency response for situational awareness. This information can be existing or dynamically created through various sensors on the building. The information can then be integrated with the indoor model and delivered to the emergency responders for mission planning and execution.

2.2 Information Requirements for Indoor Emergency Rescue Management

Availability and access to knowledge about the incident scene and situational awareness of the environment offer the rescuers valuable information that may improve their success rate in the mission and save the lives of the victims. The information on available resources, real-time information on building data and the development of the hazards, dramatically improves the safety and response capabilities of the rescue team (Holmberg & Raymond, 2013).

The rescue team, if provided with this information beforehand, would be more precise in their mission and thus not waste valuable time figuring their way around the building. They would also be exposed to less severe indoor hazards since they are aware of what to expect within the building.

Substantial studies on mission-critical information on buildings required for emergency evacuation have been carried out in numerous indoor emergencies (Yang & King, 2009). Based on these findings, the mission-critical data requisite for the creation of situational awareness for rescuers were grouped into the following;

2.2.1 Indoor Building Data:

Indoor Building Data is data about the building that is required for smoothing emergency response (Tashakkori Hashemi, 2017) ; for this project information on building orientation, 2D floor plans, building hazards, material types, designated gathering points, elevators, staircases and fire exits, construction material types, description of the building, and emergency features such as fire alarms, panic buttons, fire hydrants, hose reels, fire extinguisher points and utility shutoffs were collected.

2.2.2 Dynamic and Semantic Building Information:

Dynamic and Semantic information is information on the building which could change over a short period; examples include indoor detectors and sensors like fire sensor signals, smoke detectors, number of occupants in the building, identification of offices and occupants, and the ease of access of spaces (Holmberg & Raymond, 2013).

The access to some dynamic and semantic building information would necessitate remote access to the detectors installed within the building. Such access would, however, not be possible for this project since the detectors are quite old and had no such capabilities.

2.2.3 Outdoor Emergency Information:

This is information concerning the direct outdoor environments of the building under emergency (Yang & King, 2009); this will include surrounding buildings, the road networks and likely route of reinforcement, accessibility of the building and other nearby amenities such as hospitals, fire stations and security apparatus.

2.3 Indoor search and evacuation complexities;

First responders during emergencies such as acts of terror face challenges on their safety and their ability to save victims of the attack. Their success is dependent on, among other factors, their level of awareness with the surrounding, the knowledge of the situation such as positions of the assailants, and their ability to communicate amongst one another and with the victims. Therefore, their ability to access information regarding the building of incidence within the shortest time possible is quite vital for decision making and organising the rescue attempt (Center for the Protection of National Infrastructure & National Counter-Terrorism Security Office, 2012).

The enclosed nature of buildings often complicates the situation, sometimes its hazardous contents, occupancy conditions, obstructions and dead ends in most rooms. This information is usually not available to the rescuers beforehand if not incomplete and disorganised. Where available, the briefing would only accommodate a few people and thus necessitates a few teams to undertake the mission (Giljanovi, 2015).

These challenges may result in a haphazard search where some rooms may be skipped due to unfamiliarity and since the rescue team may have to rely on sight and sound in the primary search. The thoroughness of the primary search cannot be overemphasised since it is mainly aimed at neutralising the assailants, which if not fully achieved, puts the lives of more people in danger (Center for the Protection of National Infrastructure & National Counter-Terrorism Security Office, 2012).

In the current practice, the action plan is formulated based on 2D floor plans where such is available. These maps are difficult to interpret in stressful situations; they do not include emergency information and usually take a long time to be obtained (Tashakkori Hashemi, 2017). Compared to outdoor situations, indoor areas lack geometric and semantic information; thus, people tend to get disoriented. The inability of many people to interpret scales is also a challenge in such operations (Tashakkori Hashemi, 2017).

The level of effectiveness of a rescue mission and the attack strategy, therefore, relies a lot on the knowledge of the indoor physical spaces or situational awareness which would inform the counter-offensive routes and the escape plans by the victims.

2.4 Hazards in Public Buildings

Incidents associated with the gathering and assembly of people in public buildings have triggered the development of a vast range of building codes, regulations and guidelines globally. Significant research into evacuation and crowd dynamics attempts to understand why these incidents still occur despite standards being in place (Center for the Protection of National Infrastructure & National Counter-Terrorism Security Office, 2012).

The most extreme personal risk when gathering in public buildings is injury and death. This may occur as the direct result of a hazard, such as a fire, shooting or structural collapse, or from a crowd surge incident which may or may not be triggered by such an emergency. Even a perceived or rumoured threat can be enough to trigger a crowd incident.

Ease of building evacuation is dependent on a myriad of factors ranging from the design of the building to coordination of the rescue team. So, management of contributing factors can affect the outcomes in an emergency rescue of the victims. Common building hazards contributing to complexity in emergency evacuation in public buildings include:

i. Obstructed, locked or compromised exits and entrances;
ii. Overcrowding;
iii. Poor design creating dead-end and cul-de-sacs;
iv. Use of inappropriate materials;
v. Lack of situational awareness during emergency response.

Design guidance alone cannot guarantee safety, and managing a building's safety systems and how it is used is vital. Some of the tools used to improve building safety include:

i. Conducting audits of buildings and exits;
ii. Requiring evacuation plans, risk management plans and other emergency management plans;
iii. Assigning maximum occupancy numbers.

2.5 Role of situation awareness in indoor search and extraction mission;

Situational awareness refers to the ability to relate the cognition of an event and the reality of the crisis. High situational awareness by victims or the evacuation team eliminates surprises such as hitting dead-ends or being dodged by assailants in obscured areas. Situational awareness is adversely affected by a lack of information on the incidence building and surrounding areas. Data on situational awareness should be relayed fast and in a manner that is easy to understand since the window of opportunity is quite limited (Tashakkori Hashemi, 2017).

Situation awareness information includes the location of emergency utilities like electric shutoff, firefighting equipment; building construction material; architectural information such as floor plans, the location of emergency exits, panic rooms, other exits and staircase; semantic information like occupancy, names of office; hazardous materials such as gas lines, propane tanks; real-time information such as those from heat and smoke sensors, CCTV cameras, panic buttons in smart buildings (Mandourah, 2016).

Therefore, 3D building models able to make this information available to the rescuers rapidly is an invaluable tool during rescue missions. Being a web-based system, this information is also available to everyone thus cognition will be improved immensely.

2.6 Role of 3D maps during a crisis;

The interest in 3D mapping has witnessed an upward trajectory due to a myriad of areas of application. It may also be as a result of developments in measurement technology for collection of modelling data as well as software for manipulation. Apart from visualisation for which 3D models have been traditionally used for, today there are possibilities for simulations, analysis and planning operations. 3D maps have been used in fields like cadastral mapping, urban planning, real estate, tourism, facility management, and crisis management (Giljanovi, 2015).

In crises, it is entirely necessary to shorten the time required to extract information from a map and therefore it is necessary to adapt the map to the user's cognitive abilities. 3D maps provide better perspective view people are used to in real life and thus can be useful in a crisis. In a study by (Giljanovi, 2015) found that users were able to more successfully read the essential information in a 3D model of a volcano than a 2D contour line map.

The level of detail in the 3D model is also vital. The information provided should be just enough for decision making without leaving out mission-critical information.

2.7 3D Modelling

The popularity of 3D mapping had increased tremendously and is used in many fields as earlier mentioned. Many projects have utilised various 3D software like SketchUp and CityEngine to create augmented reality models (Kapaj, 2018a). The possibility of performing spatial analysis on such models has also widened their application. Further, the advancement to Web 2.0 has dramatically enhanced the access of such models over the internet through web browsers in the form of web scenes (Gausl, 2018).

Traditionally, 3D GIS modelling have relied on CAD data for its foundation data which was then converted to GIS data using GIS software. This kind of data however required a lot of scrubbing and organisation before they could be used for the modelling process (Kapaj, 2018b). For example, SketchUp software was used to create an evacuation plan for Montclair High School. This was achieved by converting 2D CAD floor plans into GIS data and created topology rules for implementing data integrity. The plan was then classified into rooms, windows, walls, doors, pathways and other features in 2D format. Using the SketchUp software, the 2D data was converted to 3D data using the extrusion functionality.

ArcGIS software was then used to come up with the evacuation plan using the ArcScene application (Makdoom, 2015). ESRI, on the other hand, was able to generate a 3D model of ESRI Campus in Redlands by using Computer Generated Architecture (CGA) functionality in CityEngine by customising the footprint of buildings to produce 3D models (Makdoom, 2015).

2.8 Photorealistic 3D Indoor Models

Photogrammetry has been applied to reconstruct both indoor and outdoor environments. Manual photogrammetric reconstructions are however very labour intensive and involves a lot of manual operations. This approach is therefore not feasible for large and complex assignments. The iWitness approach of (Wendt & Fraser, 2007) is an example.

The use of spherical panoramic images has been applied in creating photorealistic 3D indoor models (Anguelov et al., 2010). The 3D cameras are also fitted with laser/infrared sensors which generate dense point clouds (Pagani & Technische, 2011) which are used in reconstructing the scanned space.

2.9 Semantic Annotation of 3D Models

Indoor scene annotation is a particularly problematic area in 3D modelling of indoor spaces. Active sensors like RGB-D cameras, which provide high-resolution colour and depth information of space have improved the possibility of its automation. The ground-breaking work of (Silberman & Fergus, 2011) showed that RGB-D considerably increases scene labelling, with an accuracy of about 50% (Gould, Fulton, & Koller, 2009).

Traditional 3D modelling aimed to provide a high precision geometric representation of indoor spaces at the expense of resemblance to reality. Semantic modelling, on the other hand, strives for geometric similitude to the input (Chen, Lai, Wu, Martin, & Hu, 2014) which also fits the aim of this project. Many techniques have been devised for automatic reconstruction of indoor spaces from a set of RGB-D images; examples are those discussed in (Izadi et al., 2011).

The idyllic approach to annotating attribute data of the 3D web scene for best human perception would be a hierarchical segmentation. This is typically done by segregating regions of neighbouring matter, as related with distinct objects, object parts or group of objects, each linked with the attribute label or category (Tylecek & Fisher, 2018). Attribute annotation can be achieved through manual or automated annotation.

Manual methods of annotations require operators to enter the labels accurately, independently for all samples, which is time-consuming though more accurate. The average time spent may be reduced by providing efficient tools and friendly interfaces to the annotators. Automation, on the other hand, can introduce some bias but is much faster and efficient. It will likely guide the annotator to what is favored by the method’s data model. This may be different from what the manual result might be which are mostly subjective.

2.10 RGB-D type depth camera

RGB-D type depth cameras can sense depths as well as capture RGB images at 30 - 60 frames per second (Chang et al., 2018). The depth sensing is based on the structured light which means that the device projects an infrared (IR) dot pattern on the surfaces of the scene and deduces the depths from the measured disparity corresponding to the shift between the dots captured with IR camera and the reference model. The operational range of these devices is from about 0.8 meters to 4 meters (Virtanen et al., 2018).

In some cases, the structured light depth sensing system is replaced with a time-of-flight sensor (Khoshelham & Elberink, 2012). A generic time-of-flight sensor measures the depths by calculating the time difference between the emitted and received IR signals. The sensor measures the phase shift between the emitted and received continuous IR signals which are proportional to the time of flight (Khoshelham & Elberink, 2012).

The development of reasonably priced consumer RGB-D cameras have inspired a lot of study in their application in 3D modelling of indoor environments, particularly for robot and drone navigation. Depth camera, however, cannot be used outdoors since solar radiation affects with their active infrared sensors (Chen et al., 2018).

The geometric accuracy of depth cameras has been researched extensively and the results indicate that the random error of depth measurement varies from a few millimetres to approximately four centimetres (Khoshelham & Elberink, 2012). Depth camera sensors, over time, have become more compact and cheaper and hence many commercial products such as smartphones have integrated them (Diakité & Zlatanova, 2016).

Single depth sensors, however, have a limited field of view and are not perfect for scanning large indoor environments. For an all-inclusive and accurate 3D data acquisition, it is necessary to combine data from numerous synchronized sensors (Diakité & Zlatanova, 2016).

2.11 Indoor Positioning

The traditional approaches of developing 3D models though results in high accuracy, the output is nothing like reality since the model is untextured (Mohamed & Abdalla, 2017). The other drawbacks include the use of multiple stations in data collection, the presence of blind spots, and the need for skilled personnel. This has led to the development of mobile measurement technologies which integrates positioning, orientation and measurement.

A typical mobile measurement system comprises of Inertial Measurement System (IMS), Global Navigation Satellite System (GNSS), laser scanners, and optical cameras (Gausl, 2018). This system greatly reduces data acquisition time, is way less labour intensive, easy to operate and results in high accuracy and dense point cloud. However, this method is confined to outdoor use due to its dependence on the GNSS which is not available indoors (Tashakkori Hashemi, 2017).

In order to overcome the challenge of positioning indoors, Simultaneous Location and Mapping (SLAM) has been studied widely. SLAM solves this problem by determining positioning through motion estimation on an existing map while building an incremental map (Nikoohemat, 2013). SLAM based indoor Mobile Measurement Systems which have been built recently include NavVis M3, GeoSLAM ZEB-REVO, Leica Pegasus backpack, Matterport Pro2 3D Camera just to mention a few. These systems integrate visual SLAM and Laser SLAM and can obtain a very accurate point cloud and a 3D scene at an instant.

2.12 Summary

Management of government buildings is an area that has been overlooked by researchers especially with regards to 3D modelling partly because it is a reserve of a government department resulting in minimal literature. However, it is notable that the government premises are poorly managed and not well secured. Further, information relating to situational awareness is hardly made available to users of the buildings. Such information is also hard to access, and in some cases, non-existent hence would complicate the process of search and rescue operation should a crisis strike.

In search and rescue or counter-terrorism missions, situational awareness is quite vital both for the victims and the rescuers. Such information needs to be made available quickly and in a format that is easily understood since the reaction time is usually very brief. 3D models are therefore a better way of providing such information along with mission-critical information as it is easily understood.

There are various software for developing 3D models such as CityEngine and SketchUp using 2D CAD data as the foundation data. In order to reduce the cost of producing such models and to improve their resemblance to reality, mobile measurement technologies have been developed. These devices can capture depth and visual information which are then used to create photorealistic 3D models. SLAM technology has also been developed to help in indoor mapping where GNSS is not available.

3. MATERIALS AND METHODS

3.1 Overview

The past two chapters have discussed the background to the research problem, proposed solutions to solve the problem and reviewed the related literature enabling the actualisation of the solution. Based on this foundation, the project seeks to solve the lack of situational awareness during emergency evacuation during a crisis in public buildings by prescribing a 3D indoor model augmented with mission-critical information for the first responders. This chapter focusses on the case study, project design, methodology and research methods that were used in implementing this project. It also elaborates the project components for developing the 3D indoor model for the case study.

3.2 The Case Study

3.2.1 Location

Ardhi House is located along 1st Ngong Avenue within Community Area of Nairobi City. The General Coordinates are: 1°17'33.61" S 36°48'41.95" E. Community area of Nairobi City is located about four kilometres west of the central business district of Nairobi by road.

The Community area of Nairobi is characterised by several public buildings hosting various ministries including Ministry of Agriculture, Livestock, Fisheries and Irrigation; Ministry of Transport, Infrastructure, Housing, Urban Development and Public Works; Ministry of Water and Sanitation, Ministry of Lands and Physical Planning, and Ministry of Mining. Others include State Departments and Authorities such as The State Department of Correctional Services, The National Hospital Insurance Fund Headquarters, The National Social Security Fund Headquarters, The Kenya Universities and Colleges Central Placement Services offices, The Kenya National Library Service Headquarters, Milimani Law Courts, Kenya Revenues Authority (Domestic Taxes Department) among others.

Figure 1: Orthophoto of part of Community Area (Source: Google Earth - 2019)

Figure 2: The Location of Case Study (Marked in Red)

3.2.2 Construction Details

Ardhi House is a 12 storey commercial building owned by the Government of Kenya and houses the Ministry of Land and Physical Planning, The National Land Commission and other affiliated Committees on land. The building has a central lift lobby/staircase landing and three orthogonal wings marked A, B and C. The whole of third floor of the building is occupied by the Department of Valuation. Wing A and B are partitioned with permanent but non-load retaining walls while Wing C is mostly open plan save for three temporary partitions and one permanent partition. These spaces are largely overcrowded either with furniture or steel shelves where documents are filed.

The building is constructed of reinforced concrete framework infilled with natural stone which is externally keyed while internally plastered and painted. The lift lobby area is fitted with glazed ceramic wall tiles. The floor is constructed of a reinforced concrete slab with a glazed ceramic tiles finish. The windows are top hinged glazed steel casements which are not fitted with grilles hence creating a hazard.

The third floor is served by five passenger lifts of which one is reserved for VIPs. Each wing has an emergency exit at the rear of each wing some of which are marked while others are not. Most of the doors are fitted with Stanley automatic door closers, the main doors being fire door types.

3.3 Requirements Analysis

For any project to be successful, an analysis of its requirements has to be undertaken meticulously. The system requirements are grouped as either functional or nonfunctional depending on expectations of the output. Functional requirements are the overall performance expectations of a system while non-functional requirements are the technical and operational components of the system (Gangaputra, 2017). These requirements are shown in Table 1:

Table 1: Functional Requirements

Functional Requirements	**Description**
Indoor Network Dataset	The system has complete indoor network dataset of the building which indicates how the internal features relate.
Share Web scene	This is the capability to share the web scene through certain social media platforms;
Search capability	The users of the system will be able to search for the building name and the various offices in the building once published and made available to the public. The thumbnails can also navigate directly to the required office within the modelled space.
Mission-critical data	The model will be able to provide mission-critical data through tags on the model. The tags provide the required information when a cursor hovers on the tag.
3D Scene	The system will yield a multi-view depth map with a texture 3D model for visualisation. This will be derived from the panoramic images and point cloud. The web scene can be viewed either as a walkthrough or as a 3D floor plan.

The non-functional requirements address the operational, technical and transitional functions for the system to achieve the functional requirements. These requirements perform the background processes that enable scene manipulation. For this project, the Matterport cloud provided an integrated system which is highly automated and therefore most of the non-technical requirements were all available within the cloud. Nonetheless, the non-functional requirements used in developing this system are as tabulated in Table 2;

Table 2: Non-functional Requirements

Non-Functional Requirements	**Description**
Operating System	MacOS 10, Intel ® Core i7, 64 bit, 8.00 GB RAM, 128 GB ROM
3D Capture App	The project used Matterport Pro2 Lite 3D Camera MC250 capture app provided by the manufacturers for data acquisition, designing and customising the 3D scene produced.

Unity 5	Unity is used in the development of 3D games and simulations. Unity allows the specification of texture compression, mipmaps, and resolution settings for each platform it supports, and provides support for bump mapping, reflection mapping, parallax mapping, screen space ambient occlusion (SSAO), dynamic shadows using shadow maps, render-to-texture and full-screen post-processing effects. The Unity plugin is used in the Capture App to undertake these functionalities.
Web Publisher	The web scene was published on the Ministry of Lands Website using a link for public access but hosted in Matterport Cloud.

3.4 Apparatus

The project used Matterport Pro2 Lite 3D Camera MC250 for capturing the point cloud and the image panoramas for 3D model generation.

3.4.1 Matterport Pro2 Lite 3D Camera MC250

Figure 3: Matterport Pro2 Lite

Matterport is a mobile, tripod-mounted 3D camera that uses PrimeSense chips. The camera comprises three different integrated sensors – a thermal imaging infrared projector, an RGB camera, a thermal imaging infrared projector, and an infrared CMOS sensor which are integrated thus allowing the capture of images in HDR and depth data, which are successively connected to achieve a single 3D result, by way of a polygonal mesh. These 2D and 3D sensors capture high-dynamic-range (HDR) images and depth image data (Lehtola et al., 2017). In addition to the 3D point cloud, the RGB data is processed through an external server to obtain a 360-degree photos of 134.2 MP (1280x1024 pixels), each created by 18 images.

The nine cameras are oriented in a horizontal plane and slightly inclined downwards and upwards such that their three projection centres meet at a single point. The orientation of the cameras informs the method of scanning, which entails a complete rotation of the integrated system on the horizontal plane. The approach is divided into six stages; in each stage, the camera captures the frames which will be the final image. Then, the horizontal field of vision is fully captured at 360°, whereas the vertical plane is limited at 300°. This is because, the inclination of the sensors eliminates a part of the top and the bottom from being captured.

The 3D camera is controlled through an iPad installed with IOS application for Matterport known as the Capture App. The app controls the camera through a Wi-Fi connection. The images are transferred from the camera to the iPad in about 30 s. The Capture app is also assists in visualising the scanning progress and can also edit the scans on the go. The separation between adjacent stations should be within 1–3 m. The 3D Capture app combines the scans automatically to generate the floor plan on the fly.

Captured projects are then uploaded to Matterport's cloud servers for post-processing. The Matterport Cloud provides the tools used in creating a 3D model that includes HDR-quality images with dimensional geometry and a polygonal mesh.

3.4.1.1 Hardware Specifications

The hardware specifications were as noted below;

Table 3: Technical Specifications for Matterport (Source: support.matterport.com)

Physical Characteristics	
Size	230 x 260 x 110 mm
Weight	3.1 kg
Operating Temperature	10 to 32° C

Screen	OLED Display Screen
Electrical	
Input Voltage	15V DC
Battery Capacity	About 4 hours for continuous use;
Connections	
Mounting Connection	Female 3/8"-16 Arca-Swiss-type QR plate, permanently installed.
Wireless Connections	WiFi for transferring data from the camera to iPad using the Capture Matterport app. WiFi 802.11
Lens	4K Full Glass
GPS	In-built
Capture Performance	
Capture Resolution	4K
Camera Warmup Time	57 seconds
Capture Time per Scan	20 seconds
Depth Resolution	10 points per degree (3600 points at the equator, 1800 points at meridian, about 4 million points per panorama)
Output Pano Pixels	134 MP, equirectangular.
System Performance	
Maximum 2D Snapshot Download Resolution	8092 x 4552 pixels at 70% zoom level (36 MP)
Visual Experience inside 3D Showcase	Enhanced zooming of up to 300%.
3D Data Registration	Automatic
Maximum 360º Snapshot Download Resolution	8 MP (4096 x 2048), equirectangular
White Balancing	Automatic full-model

3.5 Data Acquisition Process

The project was carried out on the Third Floor, Wing C of Ardhi House. The floor was chosen because of the relatively lower human traffic and simplicity in design allowed for faster data collection and processing. The data acquisition process entailed the processes noted below:

3.5.1 Equipment Preparation:

The equipment necessary for the exercise were gathered and confirmed to be in working order and adequately charged where necessary. These equipment included the Matterport camera, the tripod stand, release clamp and the iPad installed with the Capture App. We also included a power bank, notebooks and sticky note pad.

3.5.2 Site Preparation:

Since the scanning would be tedious with high human traffic and also lead to alignment errors, the scanning was undertaken on the weekend of 13th April 2019. This was also done in the morning hours to avoid glare which would have interfered with the infrared depth sensors of the camera.

Once on the site, the project team explored for areas with direct sunlight, mission-critical information to be captured and areas with high occlusion. A path for data capture was then mapped by placing sticky notes where the tripod was to be stationed. These were approximately 2.5 – 4 meters apart where possible with every scan having a line of sight to the previous one.

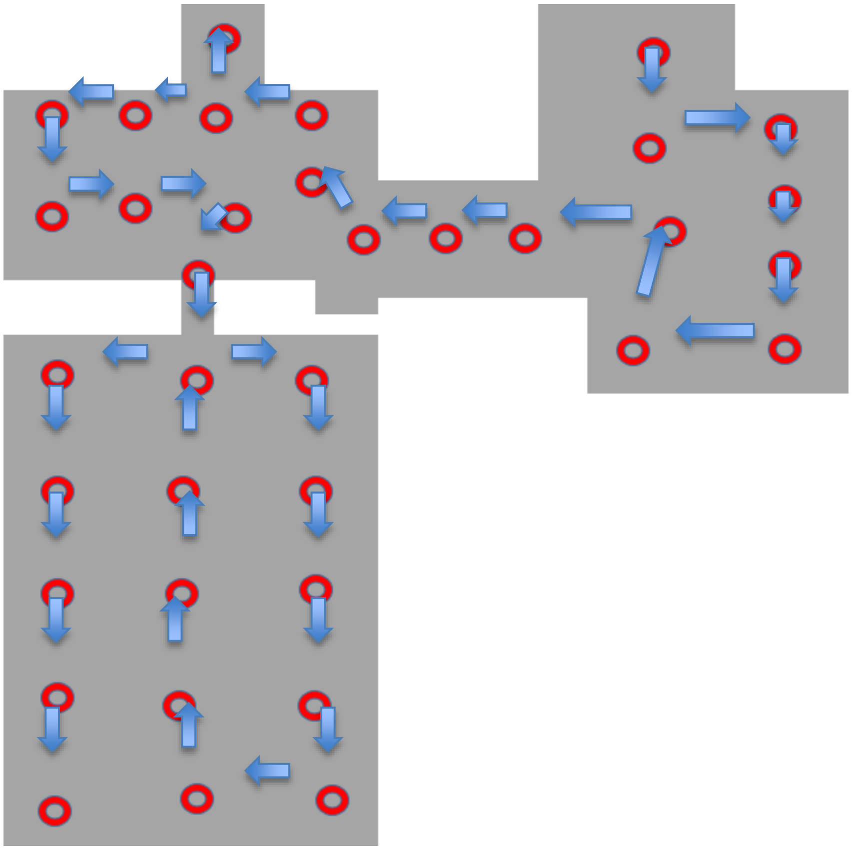


Figure 4: Planned Scanning Path

3.5.3 Scanning Process

The Matterport data acquisition process uses the camera connected to the Capture App installed in an iPad and linked through Wi-Fi direct connectivity. The result for each panorama is eighteen RGB-D images with nearly coincident centres of projection at approximately the height of a human observer.

For each environment in the case study, a set of panoramas uniformly spaced at approximately 2.5m throughout the entire walkable floor plan of the building were captured. Each room was captured individually and in some cases, more scans were taken to ensure all areas were covered and to reduce occlusion and artefacts. The captured data was uploaded to Matterport cloud for post-processing. The mission-critical data were also collected separately for later addition into the model during the post-processing.

3.6 Post-processing of Images and Depth Data

The post-processing of scans in Matterport is completed through a high degree of automation aided by a cloud computing service linked with the camera. An optimised configuration of the scans is resolved and a textured model generated from the scans and depth data uploaded to the service. The dimensional accuracy of the resulting model is estimated to be about 99% (Matterport, 2017). After processing, the 3D model and the RGB images were downloaded.

The Unity plugin within the Matterport Cloud was used in the project for creating the final 3D model. It offers an all-inclusive platform for the development of interactive 3D applications and softwares for numerous platforms, including mobile applications andweb applications with WebGL.

Unity utilises mesh models for the 3D contents that were imported into the Unity editor. It is also capable of rendering point clouds through extensions, but mesh models remain its core 3D content format.

Since we were developing a browser application, more attention was in optimising the applications to minimise memory requirement and enhance performance. This, however, reduces the use of high-resolution bitmaps and high-polygon-count meshes, and a possible shader complexity in development of the application.

In the development of this project, a memory limit of 2048Mb and the rejection of advanced shader programs were executed to allow satisfactory performance on lower-end platforms. The texture files utilised were resampled to a resolution of 1024x1024 pixels.

3.6.1 Cortex: Matterport's AI

The Matterport Cloud 3.0 platform relies heavily on artificial intelligence to power its computer vision capabilities. The AI is utilized for automating manual tasks such as blurring faces, choosing the most appealing 2D photos from data acquisition, and decide on the best content for short video clips of a 3D walkthrough. This greatly reduced the time used in editing the model and cleaning of the data.

3.7 Mission Critical Information and Building Hazards

During the data acquisition process, the respective locations and details of the mission-critical data and building hazards were captured and input into the model as tags during post-processing using the 3D Semantic Map Editor. The identified information and features are as noted below:

i. Indoor Building Data: Building orientation, material types, elevators, staircases and fire exits, construction material types, type of building, and emergency features such as emergency exits, fire alarms, panic buttons, strong rooms, fire hydrants, fire extinguisher points and utility shutoffs/main switches, dead ends and cul-de-sacs.

ii. Dynamic and Semantic Building Information: Number of staff in the building, identification of offices, overcrowded areas and the ease of access to spaces.

iii. Outdoor Emergency Information: Surrounding buildings, the road networks and likely route of reinforcement, accessibility of the building and other nearby amenities such as hospitals, fire stations and security apparatus.

iv. Building Hazards: Very narrow entrances, blocked emergency exits, dead ends, overcrowded spaces and open windows without grilles.

3.7.1 The Process of Semantic Annotation

The implementation of semantic labelling was centered on the Robot Operating System (ROS) standards and used numerous public modules which support the user interface such as those developed by (Tylecek & Fisher, 2018). ROS is a popular framework for handling and running components essential for robotic control and machine awareness. It also describes standards for data exchange, which are beneficial for recording data streams from many integrated sensors simultaneously, e.g., images from RGB-D cameras, metadata such as timestamps and coordinate system references, and camera poses (Ren, Bo, & Fox, 2012).

The data streams are stored in an archive referred to as a rosbag (Tylecek & Fisher, 2018). There are many annotation tools existing on the ROS platform. For instance, the multimedia stream annotator which is used for manual video annotation with bounding boxes. The 3D Semantic Map Editor module is another example. This is the semi-automated module utilised in incorporating mission-critical information and building hazards and is described below.

3.7.1.1 Semantic Map Editor

The graphical user interface of the 3D Map Editor has provisions for drawing a sketch map of the scene, where the 2.5D geometry of indoor environment and standalone objects has shape and semantic labels assigned to them. The annotator was used to implement the following editing actions:

i. Insert or remove vertices of the ground mesh (control points),
ii. Move a selected vertex (location X, Y),
iii. Adjust the elevation (Z) of a selected vertex or face,
iv. Insert objects of primitive shapes (spheres, cubes, cylinders, cones),
v. Change dimensions of the shapes (diameters DX, DY, DZ) and orientation (rotation angles RX, RY, RZ),
vi. Assign a semantic label from the list to a selected face of the ground mesh or object.

The 3D view mode allows panning and navigation through the model, but the objects or points cannot be moved or inserted. The module was then used to export semantic point clouds with annotations corresponding to the current 3D model.

The image labels were transferred from the current frame to the next one using the correspondences from optical flow. We use the implementation from https://github.com/suhangpro/epicflow with the default parameters.

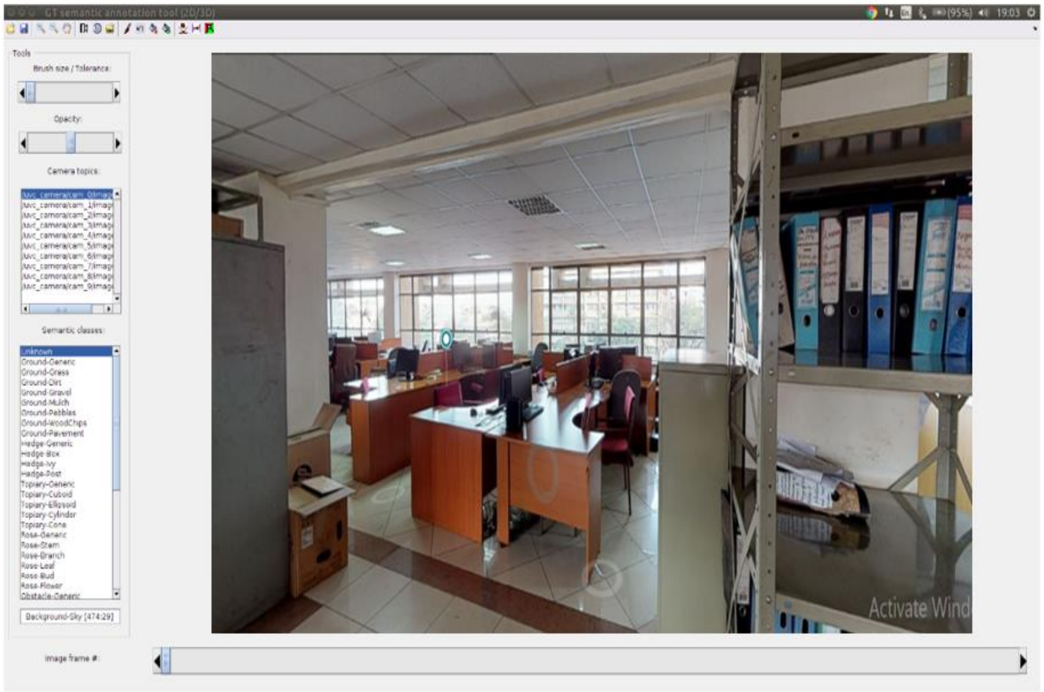


Figure 5: 3D Semantic Map Editor

3.8 Model Query

After the development phase of the project was completed, the resulting 3D model was tested to assess its response to the needs of first responders and victims by providing the mission-critical information. This was done by accessing the model through a web link of the Matterport cloud service.

Using the walkthrough feature and the 2D floor plan, space was navigated to simulate a mission briefing while checking for the location and description of the necessary information required and the need to keep oriented. The response of the model was then noted.

3.9 Summary

The Data Acquisition, processing and publication processes are summarized in figure 5:

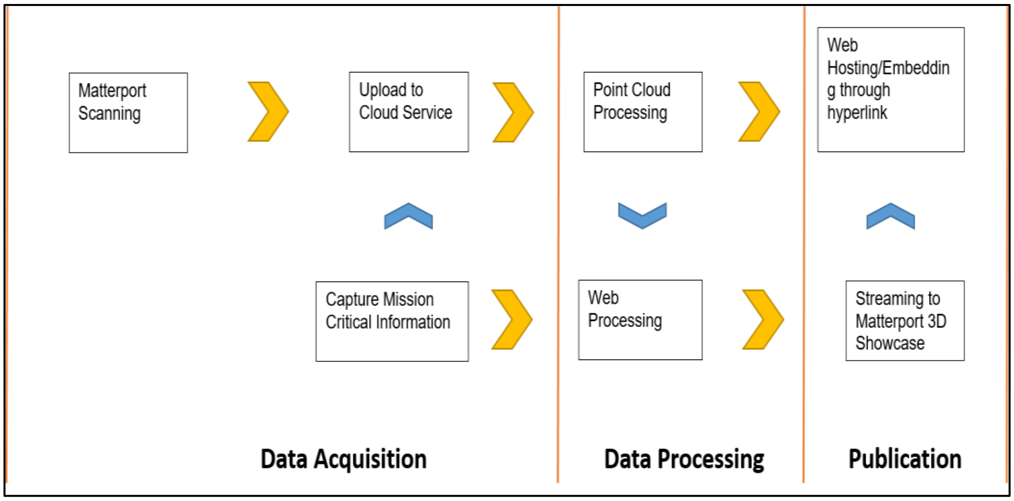


Figure 6: Data Acquisition, Processing and Publication Processes

4. RESULTS AND DISCUSSION

4.1 Overview

This chapter of the project report covers the results of data collection and their discussion in line with the objectives of the project. The project's aim was to take advantage of available 3D GIS technologies to design and develop a 3D indoor model based on mission-critical information for indoor emergency evacuation. The model broadly aimed to obtain all the spatial and attribute information required by the rescuers and the victims for a more coordinated extraction mission during a terror attack.

The model was developed using Matterport Pro2 Lite 3D Camera MC250 and the associated cloud service. The 3D camera employs various sensors including an RGB camera, a CMOS infrared active sensor, and an infrared projector allowing to capture images in HDR and three-dimensional data, which are subsequently connected to obtain a single 3D walkthrough model. The mission-critical information and the building hazards were then obtained and included in the 3D model.

The specific objectives of this project are as recapitulated below:

i. Identify specific information regarding the building that is required by the first responders and victims during an emergency evacuation.
ii. Develop a photorealistic 3D indoor model for Ardhi House, 3rd Floor Wing C.
iii. Identify potential hazards which may complicate emergency evacuation and incorporate them into the model.
iv. Query the model to assess its response to the information needs by the first responders.

Based on the above objectives, this chapter has been organised to present the outcome of the project.

4.2 Identification of Mission Critical Information

The mission-critical information was identified through literature review and was noted to include the following;

i. Indoor Building Data: Building orientation, material types, elevators, staircases and fire exits, construction material types, type of building, and emergency features such as emergency exits, fire alarms, panic buttons, strong rooms, fire hydrants, fire extinguisher points and utility shutoffs/main switches, dead ends and cul-de-sacs.
ii. Dynamic and Semantic Building Information: Number of staff in the building, identification of offices, overcrowded areas and the ease of access to spaces.
iii. Outdoor Emergency Information: Surrounding buildings, the road networks and likely route of reinforcement, accessibility of the building and other nearby amenities such as hospitals, fire stations and security apparatus.

4.3 Development of a photorealistic 3D Model for Ardhi House 3rd Floor Wing C

The result of this objective was a photorealistic 3D model of the case study derived from the RGB and depth data collected using the Matterport Pro2 Lite 3D Camera MC250.

Figure 7: Floor Plan View of the space showing feature tags.

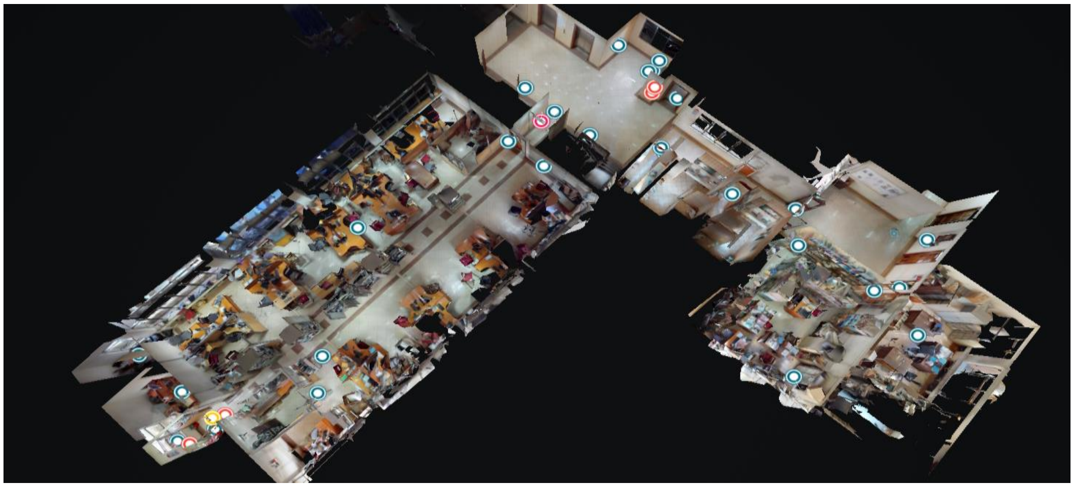


Figure 8: Dollhouse view of the 3D Model

Figure 9: Photorealistic 3D Model

Figure 10: A view of wing C

In developing the 3D model, the camera collects three types of images: RGB images, 3D point cloud and depth information.

4.3.1 RGB Images:

The RGB sensor on the camera captures raw RGB data per scan location. This information is provided both in 2D jpg format and the 360-degree jpg formats. All images in the dataset are stored in full high-definition at 1080 x 1080 resolution. The images were sampled by discarding the 15% lower entropy images thus only better quality images were retained per scan.

The RGB images are captured so as that consecutive images have an area of overlap of approximately 1 metre. The images are then stitched together into panoramas to create the 360-degree images.

Figure 11: RGB Images

Figure 12: RGB Image showing part of the corridor

Figure 13: RGB Image showing one of the rooms

4.3.2 Depth Information:

For each image, the depth information can be computed from the 3D mesh or directly from the camera from the CMOS sensor. The images are saved as 16-bit grayscale PNGs where one unit of change in pixel intensity corresponds to a 1/512m change in depth. The maximum observable range was indicated to be about 128 meters. All depths beyond this maximum distance assume the maximum value, also, pixels that correspond to locations where there is no depth information also take this maximum distance.

4.3.3 3D Point Cloud and Polygonal Mesh:

A reconstructed 3D textured Mesh model for each scanned area was obtained from the Matterport Camera. Each model contains an average of 442,716 triangulated faces and a material mapping to texture images providing a realistic reconstruction of the scanned space. The point cloud data allows for manipulation of the space and querying of information from the model.

These three datasets are combined to come up with an interactive photorealistic 3D model of the scanned space.

Triangles	442,716
☑ Vertices	1,328,148
UV Set 0	Yes
UV Set 1	No
Vertex Colors	No
Material IDs	122

Figure 14: The 3D point cloud

Figure 15: 3D Point Cloud showing different materials IDs

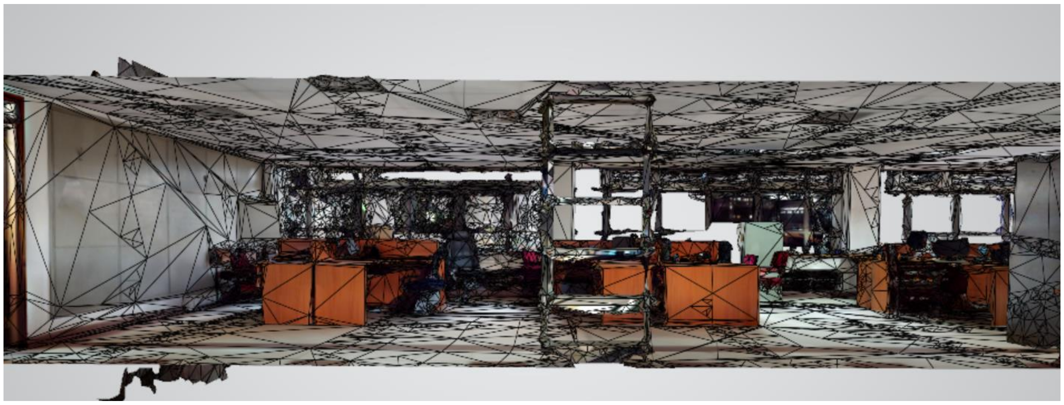


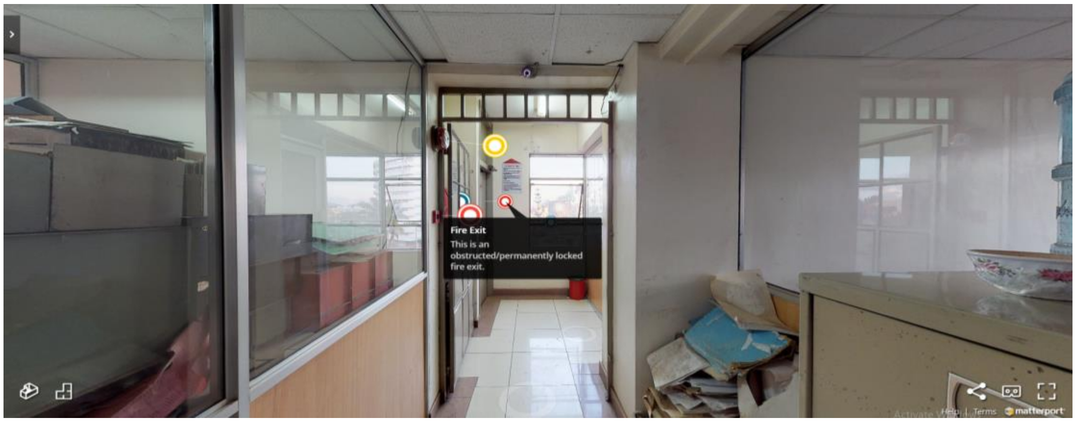
Figure 16: 3D Surface Representation as a polygonal mesh

4.4 Identification and Incorporation of Potential Hazards into the 3D Model

The following building hazards were identified during data collection and noted as follows:

i. Permanently locked emergency exits;
ii. Very narrow exits/entrances;
iii. Overcrowded Spaces;
iv. Dead-end and cul-de-sacs;
v. Wide windows with no grilles;
vi. Open garbage chutes;

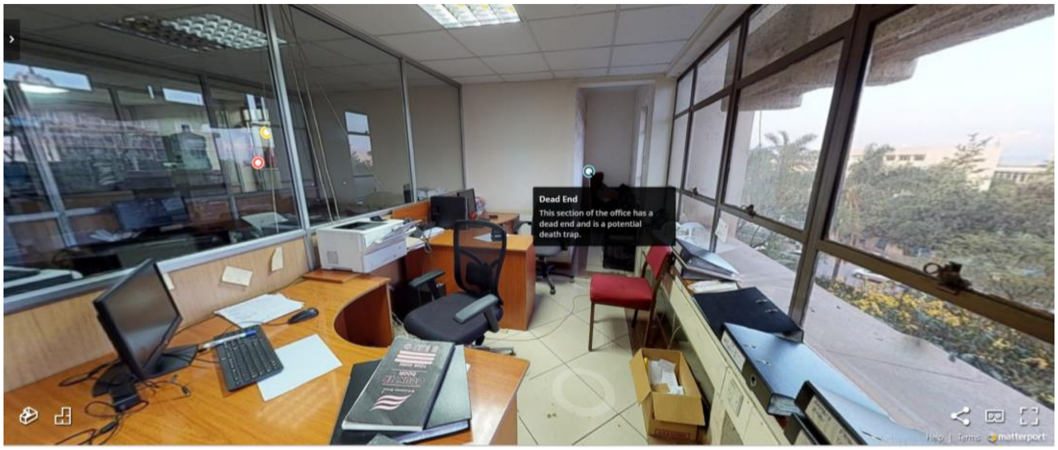
These hazards were then incorporated into the model as tags using the 3D Semantic Map Editor and Unity Plugin through the Matterport cloud service.



Fire Exit

This is an obstructed/permanently locked fire exit.

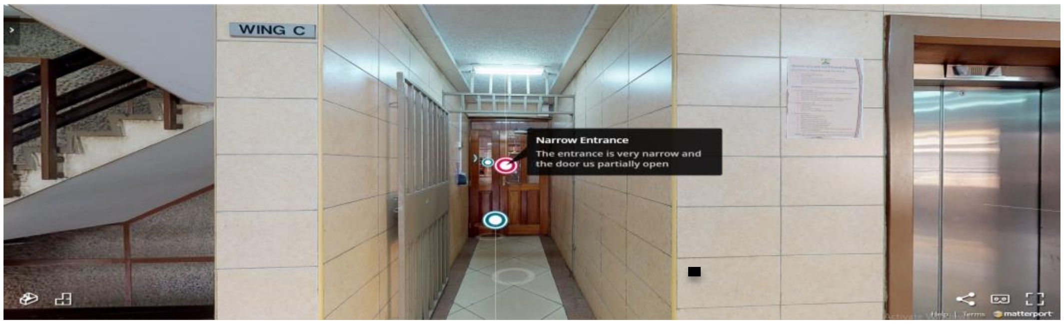
Figure 17: Obstructed Emergency Exit



Dead End

This section of the office has a dead end and is a potential death trap.

Figure 18: An example of a dead-end;



Narrow Entrance
The entrance is very narrow and the door us partially open

Figure 19: Narrow Entrance/Exit

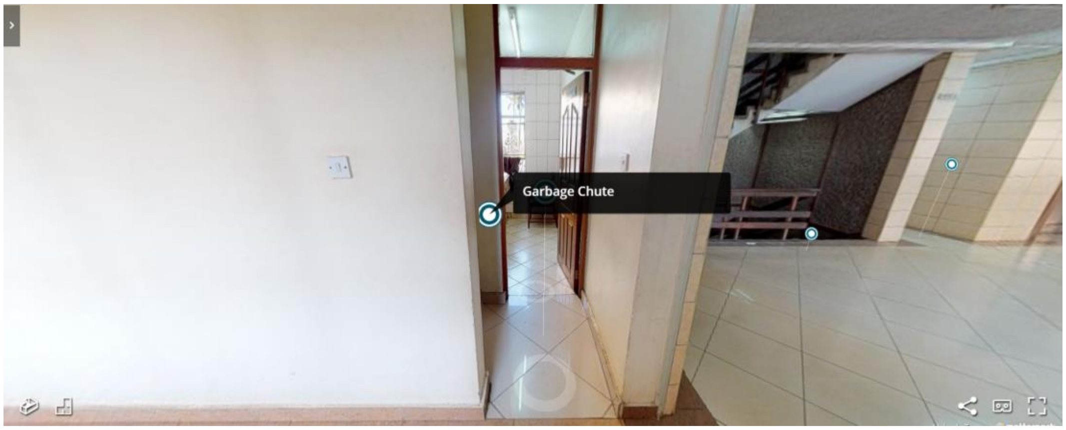


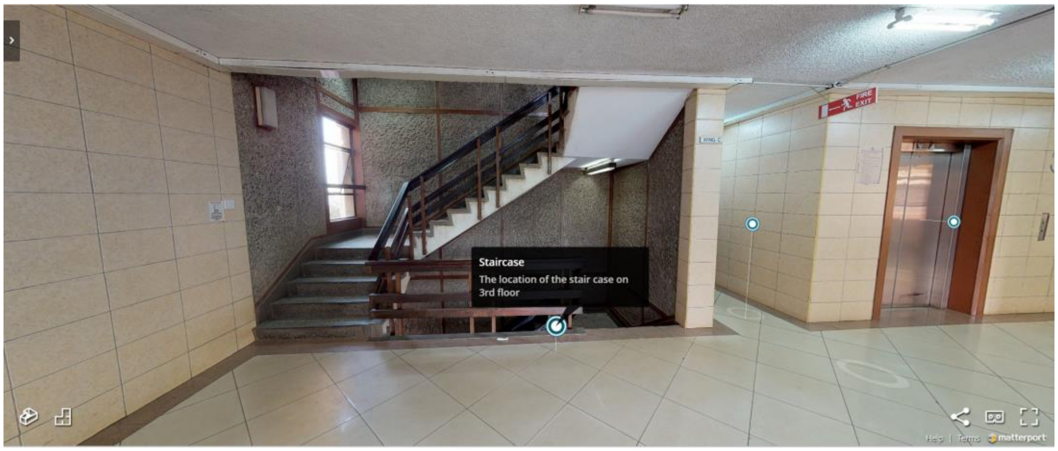
Figure 20: An open garbage chute;

4.5 Query of the Model to Access Mission Critical Information

The identified and incorporated mission-critical information can be accessed by the user of the system by navigating either through the walkthrough model or the dollhouse view of the model within the Matterport Cloud platform and hovering the cursor over the tags. The model was noted to be quite responsive without any lags in feedback provision.

The model can be panned around quite easily so as to gain orientation and for situational awareness during a mission or for identification of the nearest exit by a victim of an attack.

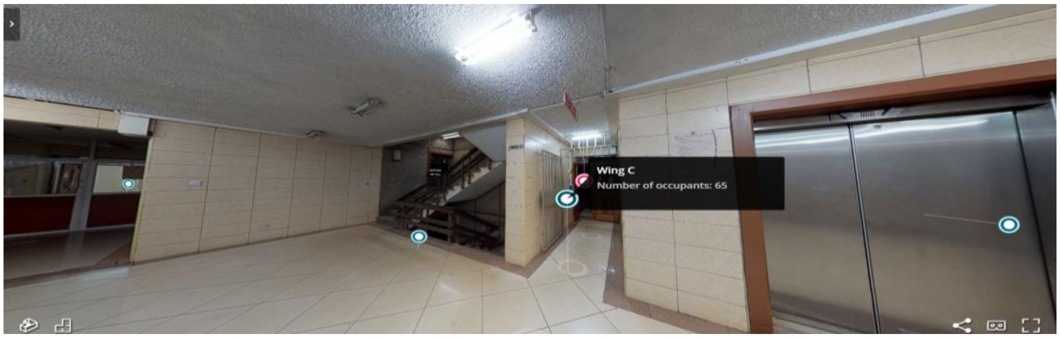
Figure 21: Panned 3D Model for visual cognition



Staircase

The location of the stair case on 3rd floor

Figure 22: Some of the Mission Critical Information



Wing C

Number of occupants: 65

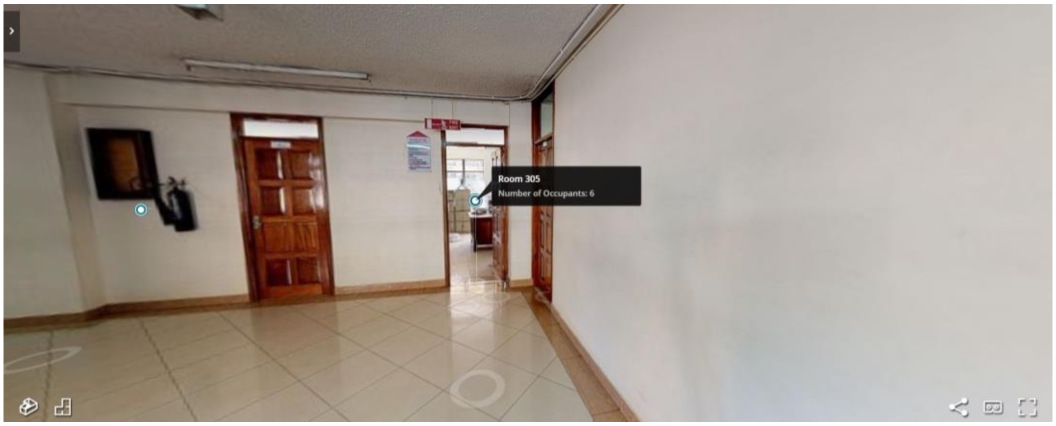


Figure 23: Office Identification and No. of Occupants

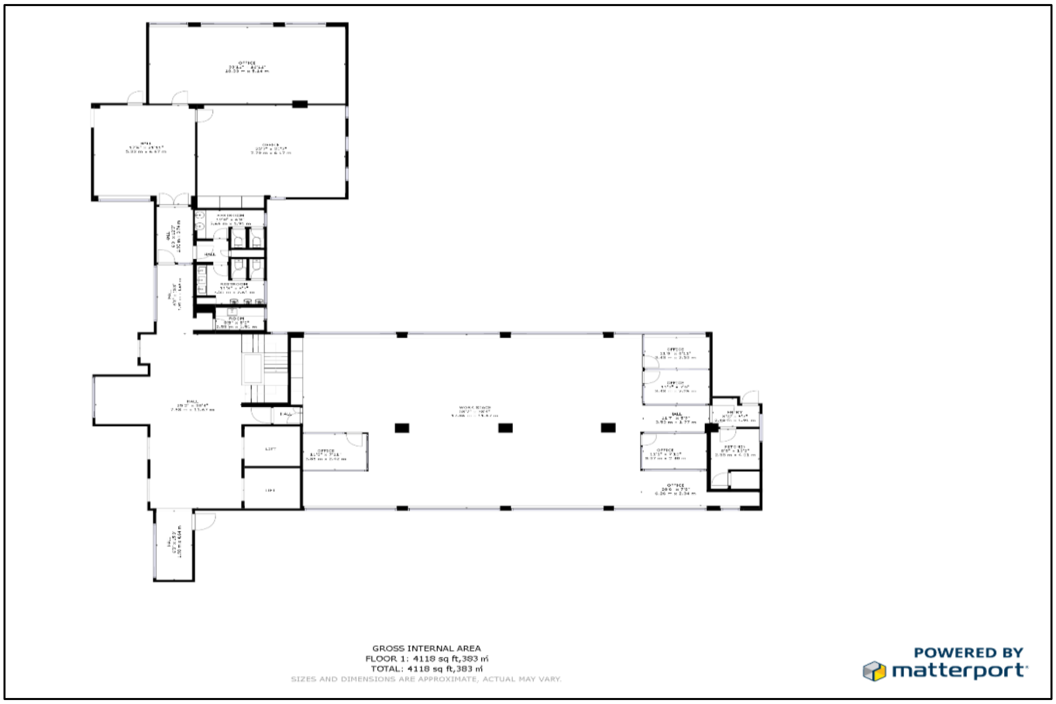


Figure 24: Schematic Floor Plan

4.6 Model Evaluation

A study by (Chen et al., 2018) evaluated the accuracy of three SLAM-based indoor mapping technologies which included SLAMMER, NAVIS and Matterport. The study concluded that the three techniques could all generate centimetre accuracy mapping result within a medium-size managed indoor environment. Matterport was noted to be a reliable tool to generate 3D indoor model. However, extra labour was needed to filter out the mismatched feature points to produce a credible 2D map.

The study further noted that the Matterport System was restricted by its terrestrial scan mechanism, range limit and sensor resolution and the density of point cloud produced which is considerably lower than those of the two other technologies. Some feature points could not be extracted either by the interactive or MBR selection. Thus extra interactive examining might be necessary to rectify the undetected results to generate the 2D indoor map. The mapping accuracy of Matterport is slightly lower than other LiDAR-based methods tested (Chen et al., 2018).

4.7 Project Limitations

Various factors limited the deliverables for this project especially based on the quality and functionality of the model. The project was severely limited by the time available to undertake the project. Due to the bureaucratic process of getting research permit on a public building and the intricacies of obtaining the camera, a lot of time was spent in organising the data acquisition process. This led to the reduction on the deliverables and the quality of the final product. The following were the limitations experienced while implementing the project:

i. The cost of undertaking this project also increased immensely deviating from the proposed budget. This was occasioned by the delay in acquiring research permits and the apparent monopoly by the Matterport Service Partners.

ii. The Matterport Workshop tools were also quite limiting in terms of functionality which was limited to just tagging and creating the 3D model. The engine was noted to be highly automated and does not provide room for customization of models. The point cloud can, however, be exported to other software such as Revit for development of BIM.

iii. During the data acquisition process, it was noted that the Capture app was somehow inefficient and kept restarting as the data acquisition proceeded. The camera also kept restarting towards the end of data collection due to overheating. It was also noted that variations in lighting conditions and displacement of objects inside the scene can affect the final result producing errors in the alignment hence new scans have to be made.

iv. In spite of a careful evaluation of scan positions, supported by the preview of previous images displayed through Matterport Capture App, the campaign phase revealed some difficulties in alignment, especially near the stairway, washrooms, areas with very bad lighting conditions and archives. This necessitated the readjustment of the position of the instrument and to perform a new acquisition to help the alignment with previous acquisitions and to guide subsequent acquisitions.

4.8 Summary

The review of the relevant literature decried the need for situational awareness in emergency rescue operations by the rescue team and victims especially during terror attacks where the risk is still imminent. It was noted that in most terror attacks meted out on innocent public building users, some of whom were visiting the building for the first time, lack visual cognition and situational awareness has led to most victims being unable to evacuate the building fast enough. Also, the first responders are often unable to access the floor plans of the building so as to coordinate the rescue mission thus leading to a haphazard extraction mission reducing the chances of success.

The project prescribed a web-based photorealistic 3D model for public buildings augmented with information identified to be of importance during the planning and execution of such operations. This model would then be made available to over the internet via a dedicated site or a link for ease of access by everyone should there be need.

The project used Matterport Pro2 Lite 3D Camera MC250 for capturing the point cloud and the image panoramas for 3D model generation. The mission-critical data and the building hazards were then added to the ensuing model at the post-processing stage using the 3D model editor and unity engine through the Matterport cloud service. The model was then tested by querying its capability to provide situational awareness and semantics on the building information which was noted to be satisfactory. The resulting augmented 3D model was then hosted on the Matterport cloud and can be accessed through https://my.matterport. com/models /hQT6 9op Rc zG ?section=media& m e diasection=showcase by the public.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main objective of this project was to create a photorealistic 3D model for management of emergency evacuation in public buildings. The case study for the project was Third Floor Wing C of Ardhi House, Nairobi. The project's missions were accomplished by using GIS technologies to meet all the objectives of the project and to deliver a responsive photorealistic model infused with semantics on building hazards and emergency rescue information. The deliverables also met all the functional and nonfunctional project requirements.

This chapter presents the conclusions and recommendations resulting from the project findings and discussions presented in the previous chapter. The conclusions are as noted below:

i. The project yielded the four expected results; the first being the identification of mission-critical information on the building. Such information included indoor building data, dynamic and semantic building information and outdoor emergency information.
ii. The project also achieved the second objective which was to develop a photorealistic 3D indoor model augmented with the already identified mission-critical data that would aid in the management of emergency evacuation. Also, the building hazards were identified and incorporated into the model thus achieving the third objective. The data acquisition and processing was efficient requiring less labour and the process completed within a short time. The model was noted to be of good quality in terms of resolution of the images and accuracy of the 2D floor plans.
iii. The final objective was to assess the response of the model when queried on the identified mission-critical information. The model responded effectively thus easing orientation, showing the location of the required information and building hazards which had been added to the model in timely manner when accessed via a bandwidth of about 5MBPS.
   The model can be applied to other disciplines such as facility management, computer aided tax appraisal, tourism and urban management.

5.2 Recommendations

The case study chosen for this project was 3rd Floor, Wing C of Ardhi House - Nairobi which is occupied by the Valuation Department of the Ministry of Lands and Physical Planning. The space was noted to be quite congested and overcrowded which would pose serious challenges should need for an emergency evacuation arise. Other hazards noted included open garbage chutes, very narrow entrances with partially opening doors, permanently blocked emergency exits and presence of dead-ends which are essentially death traps during a terror attack.

The project postulates the following recommendations;

i. This project represents a step forward in the application of GIS technologies in preserving lives through innovation. The model promises ease of access to vital information for both the victims and the rescue team during emergency evacuation and also greatly improves situational awareness and thus the project recommends its adoption in public buildings which have been identified to be constantly under terror threat and thus should be adopted in all public buildings.
ii. The 3D model was quite accurate and easy to develop and should thus be applied in other fields such as cadastral mapping, urban planning, real estate agency, tourism, facility management, automated real estate valuation which are dogged by expensive and labour intensive data acquisition and analysis.
iii. The Matterport Capture Application should be improved for a more efficient operation and shorter data acquisition time. The application may as well be made open source to encourage development in indoor modelling.
iv. The lengthy process of permit acquisition and stringent regulations to be reconsidered by the authorities. This would allow for the project to be extended to include a walkthrough with search and navigation capabilities, integration with the Google Street view for seamless navigation from Google maps for the outdoor and this model for the indoors.
v. Finally, considering the robustness of commercial modelling software such as Revit, Matterport should consider incorporating such capabilities within the Workshop. This can allow the model to be easily improved to assist during other disasters such as building collapse, fire and flood simulations using the captured point cloud. This would alleviate the inadequacies of the Matterport Workshop Module.

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