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MENG. DISSERTATION

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MOBILE PHONE TECHNOLOGY AS AN AID TO CONTEMPORARY TRANSPORT QUESTIONS IN WALKABILITY, IN THE CONTEXT OF DEVELOPING COUNTRIES

Dissertation submitted in partial fulfilment of requirements for the award of Master's Degree (MEng.) in Civil Engineering, specialising in Transport Engineering at the University of Cape Town

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DECLARATION

I, ***Wilberforce W. Chege***, hereby declare that the work on which this assignment is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part thereof has been, is being, or is to be submitted for another project in this or any other university.

Signature: Signed by candidate

Date: ………**24th January 2019**…………………….

ABSTRACT

The emerging global middle class, which is expected to double by 2050 desires more walkable, liveable neighbourhoods, and as distances between work and other amenities increases, cities are becoming less monocentric and becoming more polycentric. African cities could be described as walking cities, based on the number of people that walk to their destinations as opposed to other means of mobility but are often not walkable. Walking is by far the most popular form of transportation in Africa's rapidly urbanising cities, although it is not often by choice rather a necessity. Facilitating this primary mode, while curbing the growth of less sustainable mobility uses requires special attention for the safety and convenience of walking in view of a Global South context. In this regard, to further promote walking as a sustainable mobility option, there is a need to assess the current state of its supporting infrastructure and begin giving it higher priority, focus and emphasis.

Mobile phones have emerged as a useful alternative tool to collect this data and audit the state of walkability in cities. They eliminate the inaccuracies and inefficiencies of human memories because smartphone sensors such as GPS provides information with accuracies within 5m, providing superior accuracy and precision compared to other traditional methods. The data is also spatial in nature, allowing for a range of possible applications and use cases.

Traditional inventory approaches in walkability often only revealed the perceived walkability and accessibility for only a subset of journeys. Crowdsourcing the perceived walkability and accessibility of points of interest in African cities could address this, albeit aspects such as ease-of-use and road safety should also be considered. A tool that crowdsources individual pedestrian experiences; availability and state of pedestrian infrastructure and amenities, using state-of-the-art smartphone technology, would over time also result in complete surveys of the walking environment provided such a tool is popular and safe.

This research will illustrate how mobile phone applications currently in the market can be improved to offer more functionality that factors in multiple sensory modalities for enhanced visual appeal, ease of use, and aesthetics. The overarching aim of this research is, therefore, to develop the framework for and test a pilot-version mobile phone-based data collection tool that incorporates emerging technologies in collecting data on walkability. This research project will assess the effectiveness of the mobile application and test the technical capabilities of the system to experience how it operates within an existing infrastructure. It will continue to investigate the use of mobile phone technology in the collection of user perceptions of walkability, and the limitations of current transportation-based mobile applications, with the aim of developing an application that is an improvement to current offerings in the market. The prototype application will be tested and later piloted in different locations around the globe.

Past studies are primarily focused on the development of transport-based mobile phone applications with basic features and limited functionality. Although limited progress has been made in integrating emerging advanced technologies such as Augmented Reality (AR), Machine Learning (ML), Big Data analytics, amongst others into mobile phone applications; what is missing from these past examples is a comprehensive and structured application in the transportation sphere. In turn, the full research will offer a broader understanding of the

information gathered from these smart devices, and how that large volume of varied data can be better and more quickly interpreted to discover trends, patterns, and aid in decision making and planning. This research project attempts to fill this gap and also bring new insights, thus promote the research field of transportation data collection audits, with particular emphasis on walkability audits.

In this regard, this research seeks to provide insights into how such a tool could be applied in assessing and promoting walkability as a sustainable and equitable mobility option. In order to get policy-makers, analysts, and practitioners in urban transport planning and provision in cities to pay closer attention to making better, more walkable places, appealing to them from an efficiency and business perspective is vital. This crowdsourced data is of great interest to industry practitioners, local governments and research communities as Big Data, and to urban communities and civil society as an input in their advocacy activities.

The general findings from the results of this research show clear evidence that transport-based mobile phone applications currently available in the market are increasingly getting outdated and are not keeping up with new and emerging technologies and innovations. It is also evident from the results that mobile smartphones have revolutionised the collection of transport-related information hence the need for new initiatives to help take advantage of this emerging opportunity. The implications of these findings are that more attention needs to be paid to this niche going forward. This research project recommends that more studies, particularly on what technologies and functionalities can realistically be incorporated into mobile phone applications in the near future be done as well as on improving the hardware specifications of mobile phone devices to facilitate and support these emerging technologies whilst keeping the cost of mobile devices as low as possible.

Key Words: Walkability, Big Data, Analytics, Augmented Reality, Machine Learning, Virtual Reality, Artificial Intelligence, Disruptive Technology, Innovation, Geographic Information System, Non-Motorised Transport, Crowdsourcing, Citizen Science.

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May God bless you all.

Wilberforce W. Chege

ABBREVIATIONS & SYMBOLS

2/3D	Two/Three Dimensional
AASHTO	American Association of State Highway and Transportation Officials
Admin	Administrator
AFC	Automated Fare Collection
AI	Artificial Intelligence
API	Application Programming Interfaces
App	Application
AR	Augmented Reality
Avg	Average
BMI	Body Mass Index
BRT	Bus Rapid Transit
CAT	Call to Action
CBD	Central Business District
CO	Carbon monoxide
CO_2	Carbon Dioxide
CSV	Comma-separated values
DNA	Deoxyribonucleic Acid
ESA	European Space Agency
EV	Electric Vehicle
GB	Gigabytes
GHG	Greenhouse Gases
GIGO	Garbage In Garbage Out
GIS	Geographic Information System
GIZ	Geutsche Gesellschaft fur Internationale Zusammenarbeit
GPS	Global Positioning System
GWI	Global Walkability Index
HCM	Highway Capacity Manual
HMD	Head-mounted Display
Hr	Hour
ID	Identification
ICT	Information and Communication Technology
IP	Intellectual Property
IOM	Institute of Medicine
IOS	iPhone Operating System
IR	Infrared
ITDP	Institute of Transportation and Development Policy
JIKA	Japan International Cooperation Agency
Km	Kilometres
Kph	Kilometres per hour
LCD	Liquid-Crystal Display
LD	Least Developed
LED	Light-emitting diode
LOS	Level of Service
M	Meters
Max	Maximum
MB	Megabytes
MBT	Mini-bus Taxi
MEMS	Microelectromechanical systems

MENG	Master of Engineering
Min	Minute
ML	Machine Learning
MPH	Miles Per Hour
MR	Mixed Reality
MT	Motorised Transport
NAR	National Association of Realtors
NASA	National Aeronautics and Space Administration
NMT	Non-Motorised Transport
NOx	Nitrogen Oxide
OCR	Optical Character Recognition
OD	Origin-Destination
OS	Operating System
OSM	Open Streets Map
PC	Personal Computer
PMI	Potential Mobility Index
PNG	Portable Network Graphics
PPS	Project for Public Streets
PT	Public Transport
QA	Quality Assurance
RAM	Random-Access Memory
R&D	Research and Development
Rd	Road
Sec	Second
SIM	Subscriber Identity Module
SMS	Short Message Service
SQL	Structured Query Language
SSA	Sub-Saharan Africa
SSL	Secure Sockets Layer
St	Street
SVG	Scalable Vector Graphics
TDM	Transport Demand Management
TRB	Transportation Research Board
UA	Universal Access
UCT	University of Cape Town
UI	User Interface
UIX	User Interaction and Experience
UN	United Nations
US/USA	United States/United States of America
USB	Universal Serial Bus
USD	United States Dollar
UX	User Experience
Veh	Vehicle
VKM	Vehicle Kilometres
VMT	Vehicle Miles Travelled
VR	Virtual Reality
WB	World Bank
WHO	World Health Organization
XML	eXtensible Markup Language
TAZ	Transport Activity Zone

GLOSSARY

Artificial Intelligence (AI): The ability for a machine or software to exhibit practices, including learning, behaviour, and communication with no discernible difference from that of a human being

Augmented Reality (AR): A direct or indirect live view of a physical, real-world environment whose elements are "augmented" by computer-generated perceptual information, ideally across multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory

Big Data: The enormous volume of data –structured, semi-structured, and unstructured – that is so voluminous and complex that traditional data-processing application software is unable to handle and can be analysed for insights leading to better decisions and strategic business moves

Bodaboda: Bicycle and motorcycle taxis commonly found in East Africa

Bottom of the pyramid: The roughly 2.5 billion people that live on less than $2.50 per day

Bug (Software): An error, flaw, failure, or fault in a computer program or system causing it to behave in unintended ways or produce an incorrect or unexpected result

Central Business District (CBD): The commercial and business centre of a city

Churn: Opting to stop using a particular service and use another alternative instead, because it offers a better service

Citizen Science: Where the public participates in scientific research often in collaboration with or under the direction of professional scientists and scientific institutions

Clustering: A method for statistical data analysis, to group a multi-dimensional data set into closely related groups, such that there are similar traits within groups

Crowdsourcing: A model of sourcing whereby an individual or organisation gets goods and services, both tangible and intangible (ideas), from a substantial, fairly open, and varied/fast-evolving group of online users, in place of obtaining the function/input themselves

CSV (Comma-separated values): Simple file format used to store tabular data, such as a spreadsheets or databases

Data Analytics: The science of analysing raw data in order to make conclusions about that information

Data Aggregation: Process of aggregating (combining) data from multiple sources (such as sensors) to eliminate redundant data and only make use of the most critical and most useful data for analysis and processing

Data Mining/Data Discovery: Examining large pre-existing databases to discover patterns and generate new information

Disruptive Technology: Innovation or technology that shakes-up and drastically alters an established industry and could end up establishing a new industry altogether

Enumerator: Survey Data collector

Friction Factor: Factor describing the effort required to travel between two points

Global South: Countries located in the southern hemisphere

Kink: Similar to bug (above)

Machine Learning: The study and practice of designing systems that can learn, adjust, and improve based on the data fed to them

Matatu: Minibus or similar vehicle used as a paratransit taxi service in East Africa

Metadata: Set of data describing or giving information about other data (data about data)

Metropolitan Area: A region consisting of a densely populated urban core and its less-populated surrounding territories, sharing industry, infrastructure, and housing

Mobility: The ability to move or be moved freely and easily

Motorised: Equipment (a vehicle or device) with a motor to operate or propel it

Public Transport: A shared passenger transport service which is available for use by the general public

QR code: Type of matrix barcode (2D barcode)

Sample: A set of data selected from a statistical population by a defined procedure

SOS: Morse code for a distress call

SVG (Scalable Vector Graphics): XML-based mark-up language for describing 2D vector graphics

Sustaining Innovation: An innovation that does not affect existing markets substantially and could either be evolutionary (improves a product in an existing market in expected ways) or revolutionary (an unexpected innovation that does not alter existing markets significantly)

Target Sample: The adjusted number of individual samples or observations to include in a statistical sample for a survey

Transport Mode: Means by which people and freight achieve mobility

Urbanisation: Population shift from rural to urban residency, enabling cities and towns to grow

Urban Sprawl: The migration of a population from populated towns and cities to low-density residential development over more and more rural land. The result is the spreading of a city and its suburbs over more and more rural land

Walkability: A measure of how practical and pleasant an area is to walk

XML (eXtensible Markup Language): Type of mark-up language for encoding documents

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1. INTRODUCTION

This introduction presents the context for this research project and aids in clarifying how the fulfilment of the research aims and objectives will make a contribution to policymakers, analysts, and practitioners in urban transport planning and provision in cities, as well as the collection of transport-related data to facilitate planning.

To do so, the discussion commences with a background and purpose of the research project, and then explains the research objectives and gives a brief overview of the research project‘s approach towards a literature research. The introductory section ends with a plan of development for the research.

1.1. Background to the study

As a result of rapid population growth and urbanisation leading to challenges with congestion, the two concepts of “sustainable transport” and “equity” have emerged. Traditionally, transport planning has prioritised motorised transport over other more sustainable modes of transport and mobility such as walking and cycling. According to projections by the United Nations (UN), urbanisation coupled with ballooning population increase, could add 2.5 billion new urban inhabitants by the year 2050, the majority of whom (90%), would be in the global south developing countries of Africa, the Middle-East, Central and South America, and parts of Asia. For the first time in human history, more people now live in urban areas than anywhere else.

Since 1950, the number of cities with more than a million residents has increased from 86 in 1950, to 500 in 2015. Many of these cities in developing nations are growing at rates faster than the infrastructure can be provided, leaving out some areas that become underserved and outside formal city planning processes. This situation has created an acute need to cater to the rapidly growing problem of traffic congestion and environmental degradation primarily from vehicular emissions. The emerging middle class, which is expected to double by 2050, desires more walkable, liveable neighbourhoods, and as distances between work and other amenities increases, cities are becoming less monocentric and becoming more polycentric.

As has been expressed above, African cities are walking cities (based on the number of people that walk to their destinations as opposed to other means of mobility) but are often not walkable. Walking is by far the most popular form of transportation in Africa’s rapidly urbanising cities. For instance, 60% of trips in Ethiopia’s capital city Addis Ababa are on foot, while just 9% of trips are made in a car. In Kenya’s capital Nairobi, over 45% of people walk to their destinations. Because of this, the CO_2 emissions of these countries is extremely low. These developing countries’ denser cities and walking statistics are impressive when compared with more developed nations and have the potential to leapfrog an era of car-dominated development and evade its negative impacts. For instance, the city of London struggles to get just 20% of people to walk to their destinations and in New York; only 10-20% of trips are made on foot.

Most Africans in urban areas are, however not walking out of choice, but simply because they are unable to afford private vehicles or due to the unavailability of public transport alternatives.

African countries are thus faced with the challenge to maintain these walking levels as incomes and standards of living increase with their rapid urbanisation in recent years that is projected to continue in the future. Even though Addis Ababa has 60% of trips on foot, the city is not walkable because 63% of the streets lack any pavements, crossings (including refuge islands), or sidewalks. This explains why 67% of road accidents in Addis Ababa involve pedestrians. By 2020, road accidents are predicted to be the third-largest killer in developing countries (Gillman, 2012).

Table 1-1: Modal choice in Sub-Saharan Africa Cities

Location		**Mobility**	**Modal Split (%)**			
Country	**City**	**#trips/person/day**	**Walk**	**Cycle**	**Public Transport**	**Private motorised Transport**
Kenya	Nairobi	2.2	47	1	42	7
	Eldoret	2.7	48	12	24	16
Tanzania	Morogoro	1.7	67	23	12	4
	Dar es Salaam	1.9	47	3	43	7
Ethiopia	Addis Ababa	4.9	70	-	26	4
Congo	Kinshasa	2.2	70	-	20	10
Mali	Bamako	3.1	60	2	17	21
Zimbabwe	Harare	N/A	63	1	16	20
Burkina Faso	Ouagadougou	3.8	42	10	3	45
Senegal	Dakar	3.2	81	1	17	1
Niger	Niamey	N/A	60	2	9	32

(Terlouw, 2006)

To further promote walking as a sustainable mobility option, there is a need to assess the current state of its supporting infrastructure and begin giving it greater priority, focus and emphasis. Data collection on walkability is carried out using integrated techniques such as GIS, questionnaires (community perception studies) and audit tools that focus on the functional and physical environment, land use, density, and other related factors (Kermani et al., 2018). There are tools already in the market using GIS analysis to identify areas to prioritise public and non-motorised transport. These tools however often rely on quantitative, objective measures such as footpath widths, and pedestrian green time, but often do not fully incorporate the influence of the built environment or other subjective measures.

Mobile phones have emerged as a useful alternative tool to collect this data on the state of walkability in cities. Since the early 1990s, the network of land-based cell phone towers has been used to triangulate the location of the mobile phone user as a means of tracking and collecting travel data. In the subsequent years, these applications have evolved with the development and onset of mobile applications that leverage web-based services, allowing users to access a range of information while on the go, but also share information about the cities within which they live and commute. Information on routes frequented, arrival and departure times, journey distances and trip times, no longer need to be obtained from survey respondents if smartphones are used. This eliminates the inaccuracies and inefficiencies of human memories by instead having location-aware smartphones equipped with GPS chips, which will provide that information with accuracies to within 5m. Smartphone data has superior accuracy and precision to traditional methods which relied on recall by respondents, often presented with human errors. A key advantage of using mobile phones for such assessments is that the data is spatial in nature, allowing for a range of possible applications and use cases. Consequently, these technological advances have created opportunities for obtaining real-time feedback on perceived challenges associated with walking.

Previous research has already shown that mobile phone owners typically make social trips further away than people without mobile phones (Goodyear, 2012). The ability to find destinations and directions with information technology, inspires people to travel beyond their "cognitive maps," which are the schematics held in our minds of our home environments. The ability to easily and conveniently carry information on our smartphones, such as cell phone map navigation technology, might make people feel safer and more likely to venture and explore new places. This could have the effect of bringing much-needed activity and revenue to previously marginalised far-flung areas. Research has found that people who walk understand their surroundings better and can more accurately estimate distances to landmarks than passengers or transit users (Goodyear, 2012). Additionally, children driven everywhere rather than being able to walk or ride bicycles have a diminished awareness of their surroundings and neighbourhoods (Goodyear, 2012).

This research investigates the use of mobile phone technology in the collection of user perceptions of walkability, and the limitations of current transportation-based mobile applications, with the aim of developing an application that is an improvement to current offerings in the market. The research will present the framework of a prototype of the mobile phone application that will be tested in five locations around the globe; Nairobi (Kenya), Ottawa (Canada), Enschede (Netherlands), Java (Indonesia), and Cape Town (South Africa). Past studies are primarily focused on the development of transport-based mobile phone applications with basic features and limited functionality, which do not factor in multiple sensory modalities for enhanced visual appeal, ease of use, and aesthetics. Limited progress has been made in integrating emerging advanced technologies such as Augmented Reality (AR), Machine Learning (ML), Big Data analytics, among others into mobile phone applications; however, what is missing from these past examples is a comprehensive and structured application in the transportation sphere.

1.2. Justification for the Research

According to projections by the United Nations (UN), urbanisation combined with ballooning population increase could add 2.5 billion new urban inhabitants by the year 2050, the majority of whom (90%), would be in the global south developing countries. Most of the research in this area, including the extensive work done by experts in the field such as Dr Karl Kim (PPS, 2011), Adrian Ghenadenik, and Professor Barnett (Ghenadenik, A; Barnett, T, 2018), has unfortunately not only focused primarily on wealthier developed countries of North America, Europe and various parts of Asia, but also paid little attention to the availability and state of pedestrian infrastructure and amenities. Motorised transport has historically been prioritised over other modes of transport and mobility. Traditional inventory approaches often only revealed the perceived walkability and accessibility for only a subset of journeys. Crowdsourcing the perceived walkability/accessibility of points-of-interest in African cities could address this, albeit aspects such as ease-of-use and road safety should be considered. Whilst local governmental public road plans mostly focus on individual roads, it is the perceived walkability of a complete journey that is of relevance in the decision-making processes as the various means of mobility are evaluated. For example, when reaching a hospital or clinic, an informal settlement dweller may have to traverse a few key sections that are perceived as unsafe or cumbersome while the majority is considered walkable.

Inventorying these perceived barriers would help prioritise public road planning efforts such that walking becomes the preferred mode of mobility. It is vital for there to be research to appraise and complement these shortcomings and information gaps in secondary data sources. A tool that crowdsources individual pedestrian experiences; availability and state of pedestrian infrastructure and amenities, using state-of-the-art smartphone technology, would over time also result in complete surveys of the walking environment provided such a tool is popular and safe. This is what is to constitute the outcome of this study. This research project attempts to fill this gap as much as also bringing new insights, and thus promote the research field of transportation data collection audits, with particular emphasis on walkability audits. In order to get policy-makers to pay attention to making better, more walkable places, appealing to them from a business perspective is critical.

On the other hand, most foreign technologies, firms and start-ups are falling short when it comes to addressing the needs of the vast majority of city residents in the global south. Even when the technologies are widely adopted, they only really serve the elite and exclude the urban poor who are the majority of residents in developing cities, and often have different priorities. Most of the available technologies were designed to serve cities in the developed world and are then retrofitted to attempt to serve the same functions in the global south developing world. This approach does not always work as intended as they are ill-suited to local realities. In recent years, a realisation of this shortcoming has led to a new trend where these technologies are increasingly being developed in emerging economies, and we see the rise of home-grown technology solutions for the "bottom of the pyramid." This term refers to the roughly 2.5 billion people that live on less than $2.50 per day which often includes the urban poor (United Nations, 2016).

Furthermore, the proliferation of mobile phone-based telecommunication services and smartphones in developing countries has created a viable case for the development of technological solutions incorporating the participation of the public through means such as crowdsourcing. This proliferation has allowed these countries to leapfrog the traditional landline-based communication directly into the digital phase, as illustrated in Figure 1.1 below. Despite increasing mobile phone and internet penetration, many developing countries are still faced with a myriad of barriers and limitations preventing greater coverage. Among these barriers are the relatively low digital literacy rates and the lack of adequate infrastructure including antennas, telephone masts, fibre optic cables, limited spectrum availability, underdeveloped national core networks, among others. It is often difficult to put up such infrastructures in rural areas where most of the unconnected live, because of the lack of adjacent infrastructures such as roads and electricity, thereby increasing the costs faced by network operators to extend coverage to these areas (McKinsey&Company, 2014).

Even with the increasing utility of the Internet in providing access to information, opportunities, and resources to improve quality of life, many people in these countries lack sufficient incentive or compelling reasons to go online. This is often because of a lack of awareness of the Internet or use cases that create value for the user, a lack of relevant (that is, local or localised) content and services online, and a lack of cultural or social acceptance. In addition to this is the high cost of accessing devices and data bundles particularly considering the low incomes of the populace, many of whom are in rural areas and likely have other more pressing priorities (McKinsey&Company, 2014).

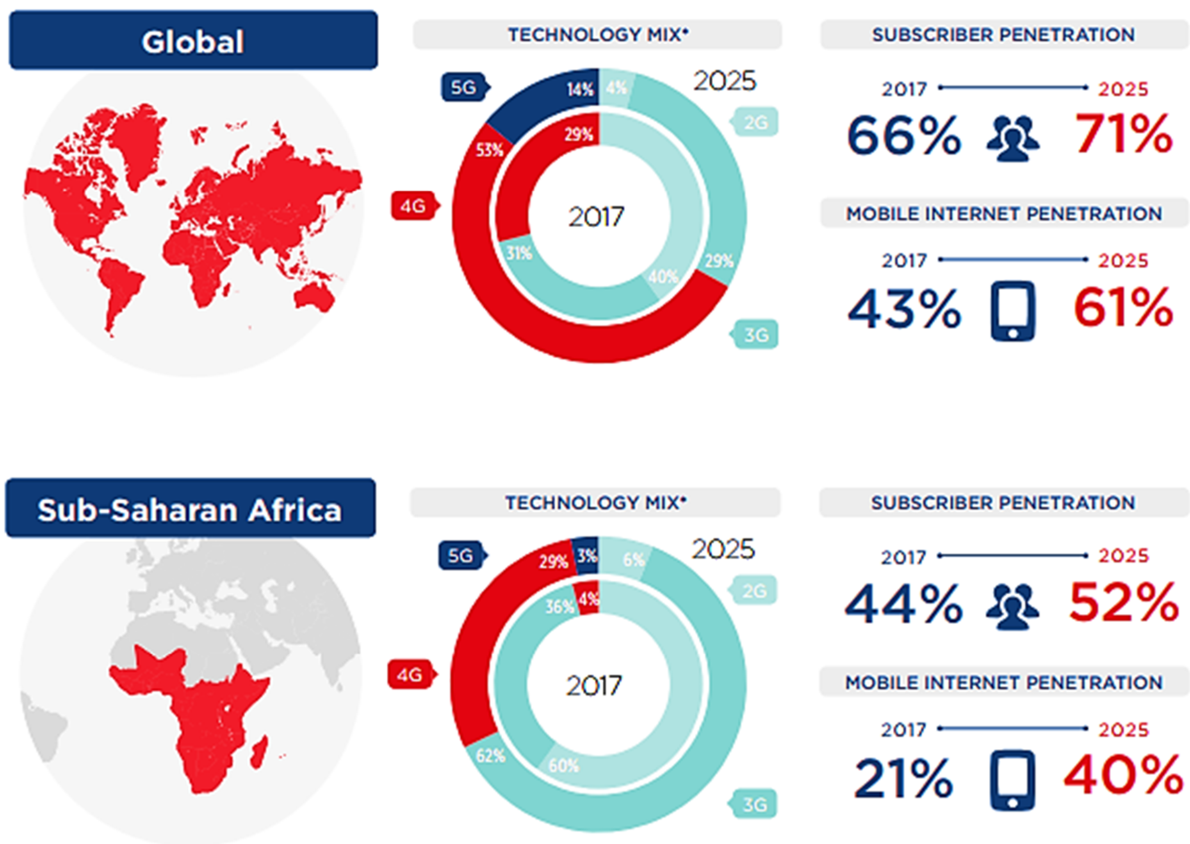


Fig. 1.1: Mobile phone penetration rates

(Pew Research Center, 2015)

In Africa, the current average mobile penetration rate of 44% is below the global average of 66% though it is forecast to reach 50% by the end of 2023, and 52% by 2025 (GSMA, 2018). Taking the example of the developing country of Uganda that is typical of other developing nations, it had a penetration rate of 42.9% and a 47.4% internet growth rate between 2000 and 2017. As early as 1999, Uganda became the first country in Africa having the number of mobile subscribers surpassing the number of fixed-line users; a ratio that is now at 18:1 (GSMA, 2018).

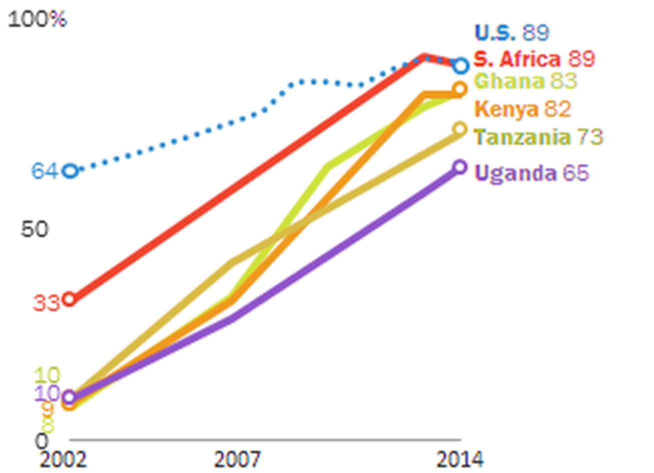


Fig. 1.2: Proportion of adults that own a mobile phone

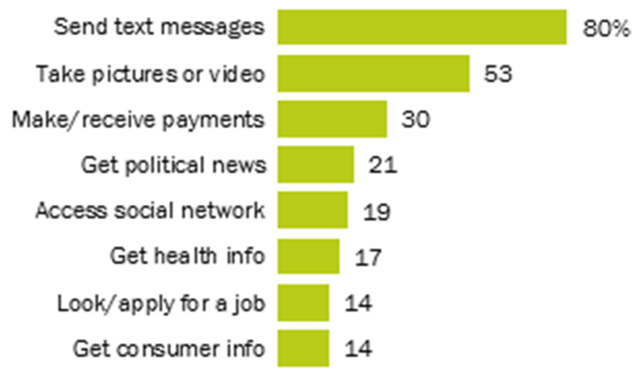


Fig. 1.3: Most common uses for mobile phones in Africa

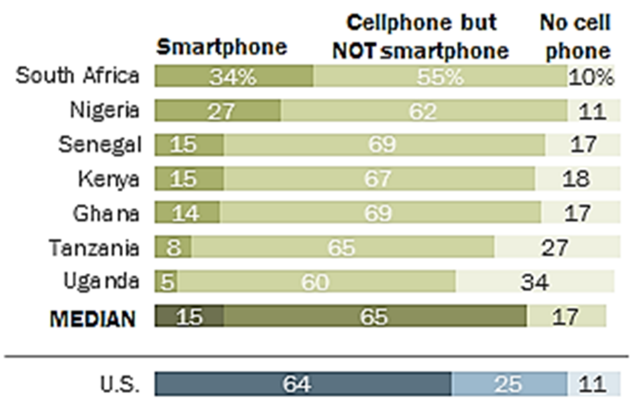


Fig. 1.4: Type of mobile phone

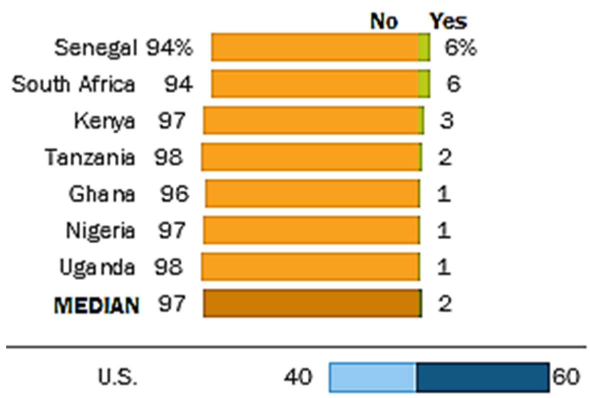


Fig. 1.5: Proportion of African households that have a working landline

(Pew Research Center, 2015)

The most common use of mobile phones in Africa is sending text messages and taking pictures and videos. In East Africa (Kenya, Uganda and Tanzania), mobile phones are commonly used for mobile money transfer through services such as M-Pesa. In Uganda, 93% of people with secondary education or higher, own a mobile phone, compared to 75% of those who speak or read at least some English that does, while only 48% of those with no English language skills own one. 77% of Ugandan men own a mobile phone, while only 54% of Ugandan women do, and greater gender disparity is seen in most other African countries (Pew Research Center, 2015).

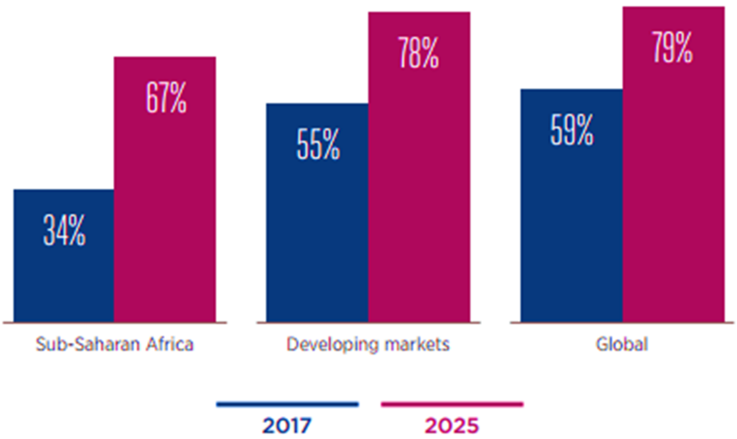


Fig. 1.6: Smartphone adoption rates

(Pew Research Center, 2015)

Africa is approximated to have over a billion live sim connections and 300 million additional people going online by 2025. The mobile ecosystem will support 3.45 million Jobs by 2023, and it will add more than $150 billion in value to Sub-Saharan Africa's economy by 2022, equivalent to 8% of regional GDP. A key driver of smartphone adoption is the growth of entry-level devices at affordable prices, often from more price-focused brands from Chinese manufacturers such as TECNO, Infinix, and FERO MOBILE. Mobile broadband is projected to account for 87% of the mobile connections in Sub-Saharan Africa by 2025, up from 38% in 2017. Over the last three years, the average price of a smartphone in Uganda has decreased by 45%, from $178 in 2014 to $99 (Twaha, 2017). The Android One program by Google, for example, has launched dual-SIM, micro-SD card slot for memory expansion, and 4.5-inch capacitive touchscreen display smartphones in emerging markets for $100. It was launched in 2014 and intended for first-time smartphone users in emerging markets.

Phones using either 3G or 2.5G EDGE networks are the leading platform for Internet access in Africa allowing people to bypass the limited reach of the fixed broadband network. 3G is predicted to be the dominant technology in Africa accounting for 60% of connections by 2025 (GSMA, 2018).

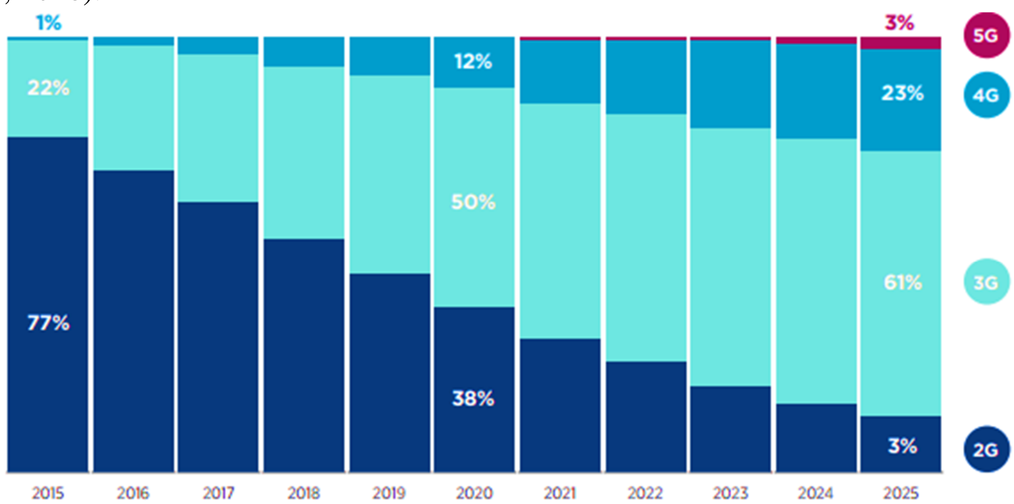


Fig. 1.7: Mobile network penetration

(Pew Research Center, 2015)

In the final analysis, the statistics paint a picture of a continent that will experience high growth rates of mobile phone ownership and digital literacy within the next decade. It is, therefore, the right time to create innovative solutions to take advantage of this growth. Inclusive innovation recognises the operating environment, and thus develops solutions, products and services tailored to the realities of that environment. An example of an inclusive technologically innovative local solutions is the humanitarian cash transfer project in northern Uganda. The country is the largest recipient of fleeing migrants in Africa, with daily new arrivals of 3,000 refugees and in less than a year, the refugee population has doubled to 1.3 million, mostly from war-torn South Sudan. Because of the increasing mobile phone penetration in Uganda, humanitarian organisations have collaborated to deliver humanitarian assistance through humanitarian cash transfers to refugees via mobile money. Leveraging mobile money for such transfers reduced logistical costs, giving refugees greater dignity, choice, and potential for financial inclusion (GSMA, 2018).

In turn, this research will offer a broader understanding of the information gathered from these smart devices, and how that large volume of varied data can be better and more quickly interpreted to discover trends, patterns, and aid in decision making and planning. By assessing the degree to which the built environment supports or degrades walking, targeted urban and transportation planning can be enhanced and promoted, while also promoting sustainability. In the long run, there is also a need to understand the barriers that inhibit walking and discourage more people from churning towards walking as opposed to motorisation to meet their mobility needs. It would make it easy to share relevant information on the walkability of streets for further research, as opposed to the tedious, manual auditing efforts currently in place, ultimately aiding toward the betterment of public spaces for pedestrians.

This research banks on the idea that the desire for more walkable pedestrian-friendly cities is not merely a fad in urban development, rather a long-term trend towards more awareness of the civic and economic benefits of more walkable urban environments.

Furthermore, this document will be made available to other researchers as a source, and thus help improve the body of literature in this field. The outcome of this research project will be useful to policymakers, analysts, and practitioners in urban transport planning and provision in cities. The crowdsourced data is of great interest to industry practitioners, local governments, and research communities as Big Data, and also to urban communities and civil society as an input in their advocacy activities.

1.3. Research aims and objectives

The overarching objective of this research is to identify and analyse the emerging technological innovations that can be applied to improving an existing smartphone application tool, and how these new technologies can aid in collecting information on walkability and in the tackling of walkability challenges in the context of developing countries, particularly those in Africa. The aim is therefore to develop the framework for and test a mobile phone-based data collection tool that incorporates new emerging technologies in collecting data on walkability. This will be done by translating a set of transport demand questions as pertains to walkability, into an architectural design of a mobile smartphone application. The research will assess the effectiveness of the mobile application and test the technical capabilities of the system to experience how it operates within an existing infrastructure. The existing application provides a business-as-usual case that needs new (disruptive) technologies to improve and advance further. A future application will be developed as an improvement of the existing prototype application developed and tested in collaboration with Ujuizi Labs.

The literature review, in particular, aims to identify the most pertinent challenges with the use of mobile phone technology in the collection of user perceptions of walkability, and the limitations of current transportation-based mobile applications, to develop an application that is an improvement to current offerings in the market. It will review literature on the new and emerging technologies and innovations pertaining to walkability assessments using mobile phone devices. Limited progress has already been made in integrating new and emerging technological innovations and functionalities such as Augmented Reality and Machine Learning into mobile phone applications. What is however missing from these past examples is a comprehensive and structured application in the transportation sphere.

The author will therefore attempt to provide insights into the following questions:

1. What is walkability, and how is it assessed and quantified?
2. How can it be promoted as a means to improve sustainability?
3. How has mobile phone technology been leveraged in urban city and transportation planning, and how have mobile phone devices, particularly smartphones, been used in the collection of walkability-related data?
4. What are the limitations and shortcomings of the current transportation-based mobile applications?
5. What are the emerging technological innovations that can be applied to improving the current application offerings in the market, and how can these new technologies aid in tackling walkability challenges in the context of developing countries?
6. What are the technical and functional requirements for mobile smartphone devices to support these technological innovations and advanced functionalities?

The tool could thus be used to collect data on the pedestrian experience, including the availability and state of pedestrian infrastructure and amenities, and facilitate in-app surveying of the walking environment using crowdsourcing, Artificial Intelligence, and human intelligence. Users, in this case, rate their walking environments along the following aspects: crossing safety; maintenance and cleanliness; motorist behaviour; modal conflict; security from crime; obstructions; availability of street crossings (such as refuge islands); pedestrian amenities, street lighting; disability infrastructure and sidewalk width; and volume of use.

To attain a broader perspective, this study also briefly addresses the situation in other Sub-Saharan African cities in general. From those findings, further research can then be carried out on what other technologies could be incorporated for smoother, more accurate results and increasing mobile phone application usage in developing nations. An online dashboard will be provided along with the application to allow for the storage and visualisation of the users' perception data and multimedia captured using the smartphone application. The tool will provide a shift away from the mechanistic approach to understanding pedestrian challenges and facilitate the prioritisation of walking as a more sustainable and equitable means of mobility. The methodological approach employed to meet the research aims and objectives is discussed in detail in Chapter 2 of this report.

1.4. Plan of development

This research project is comprised of five chapters. The foremost chapter outlines the area of interest and gives an introduction to the study, the problem that is being investigated and the aims and objectives of the study. A plan of development of the research is outlined in this section, and the methodology used is discussed in Chapter 2.

Subsequently, a review of the literature on walkability audits and the emerging technological paradigms in mobile phone app development is presented and summarized in Chapter 3 of this report, with a focus on Big Data, Augmented Reality and Machine Learning. The literature review begins by analysing various scholarly studies and reports on walkability, which is a measure of how practical and pleasant an area is to walk and will be explained in more detail in section 3.2, and why it is essential to study and cater to it. It then proceeds to a more in-depth discussion on these identified characteristics, and on how walkability can be measured and quantified. This is followed by a discussion of the nature of disruptive technology and an outline of the various disruptive innovations that could be incorporated into mobile phone applications geared at determining the level of walkability. It continues to discuss the rationale and framework of a mobile application to crowdsource data on walkability, and its development and testing processes and continues to outline how to analyse the crowdsourced data obtained.

Chapter 4 presents the technical and functional requirements for the application and the features list for that application. Chapter 5 discusses the results of this research while Chapter 6 of this report ties all this information together in the form of a summary and conclusions drawn along with recommendations for further study and investigations into the enhanced use of mobile phones for conducting walkability audits.

2. RESEARCH METHODOLOGY

The primary objective of this study is to provide an overview of emerging mobile phone technologies pertaining to walkability, in a context to recommend the further development of an existing tool that represents the business-as-usual case. To do this, an extensive review of literature and theoretical analysis of the framework, identify needs, gaps, and requirements for such an application will be conducted. The selection and discussion of theoretical and descriptive material, in the context of the latest technological advances in mobile application development, will then be presented.

After extensive literature review, the research begins by identifying the relevant research questions then proceeds with a detailed discussion of the mobile application development process including various mobile application characteristics, issues and challenges, and best practices adopted by software developers for a successful smartphone application development process. The needs of stakeholder groups define what they expect from the application, and that is a crucial component of what informs the features and functionalities incorporated into the prototype. The solution requirements describe the characteristics that the application must have in order to meet the needs of the various stakeholders. These stakeholders could include Government, City authorities, interest groups, and members of the public particularly communities residing in underserved areas in terms of provision of transportation infrastructure. The internal stakeholders, on the other hand, include the development team and the alpha and beta stage testers of the application.

The research continues to report on the various issues and challenges faced while developing this *Walkability* application, the key features that define a great application, categories and the unique characteristics of these applications, and ultimately the application development best practices. The testing of the features of the prototype application is later done in five locations around the globe. These are; Nairobi (Kenya), Ottawa (Canada), Enschede (Netherlands), Java (Indonesia), and Cape Town (South Africa).

The methodology followed is summarised in Figure 2.1 that shows the how the transportation challenges experienced in the least developed countries, the friction factors (and various walkability parameters) that travellers consider which also determine the quality of a trip, are linked to the available technologies, including newer disruptive technologies, that can be used to tackle the challenges. These, in turn, leads to the design roadmap which informs the needs, requirements, and specifications of the application. It provides information that can be used when transport-related smartphone applications are developed. The application design process is then further elaborated in Figure 2.2.

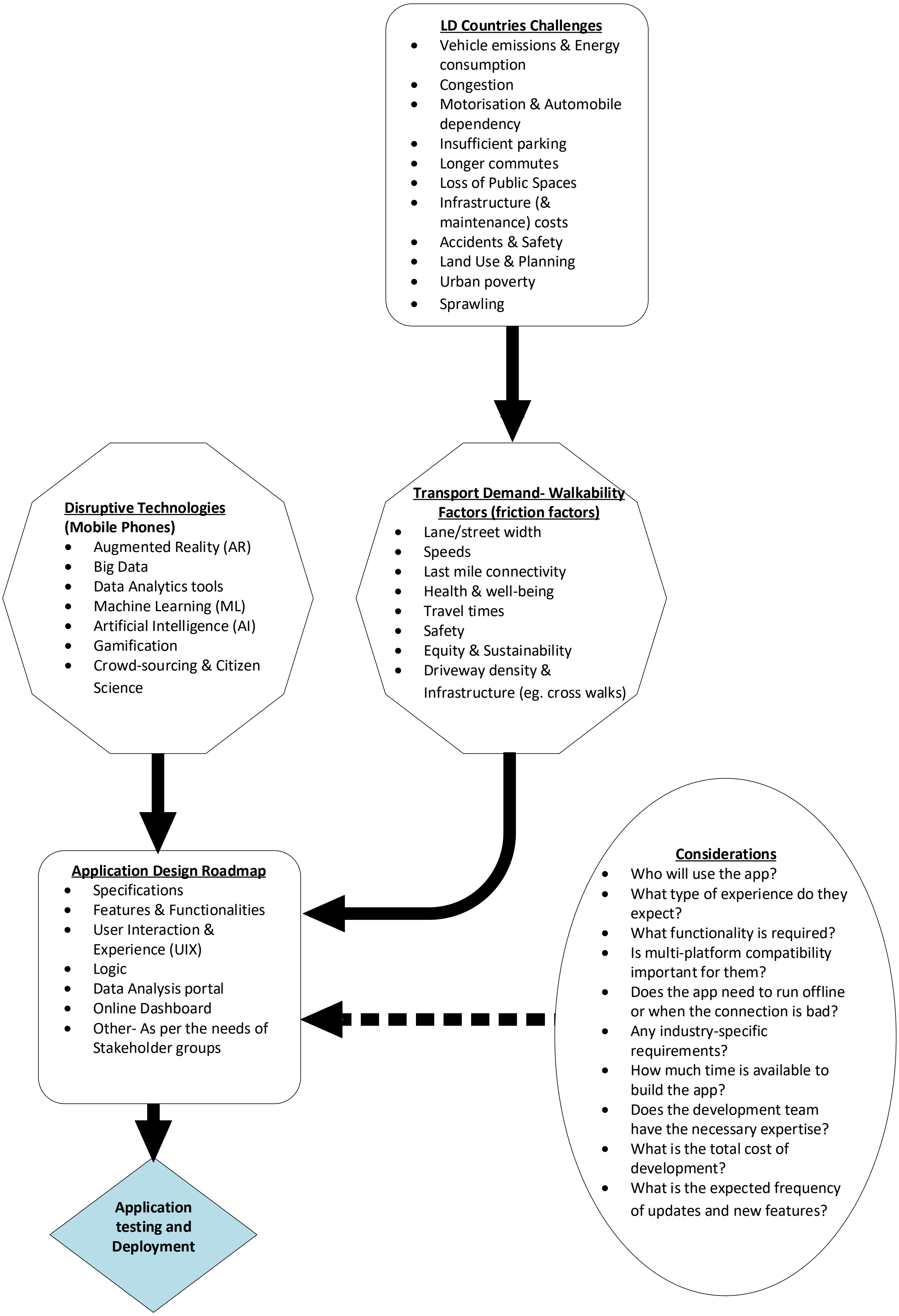


Fig. 2.1: The research design process

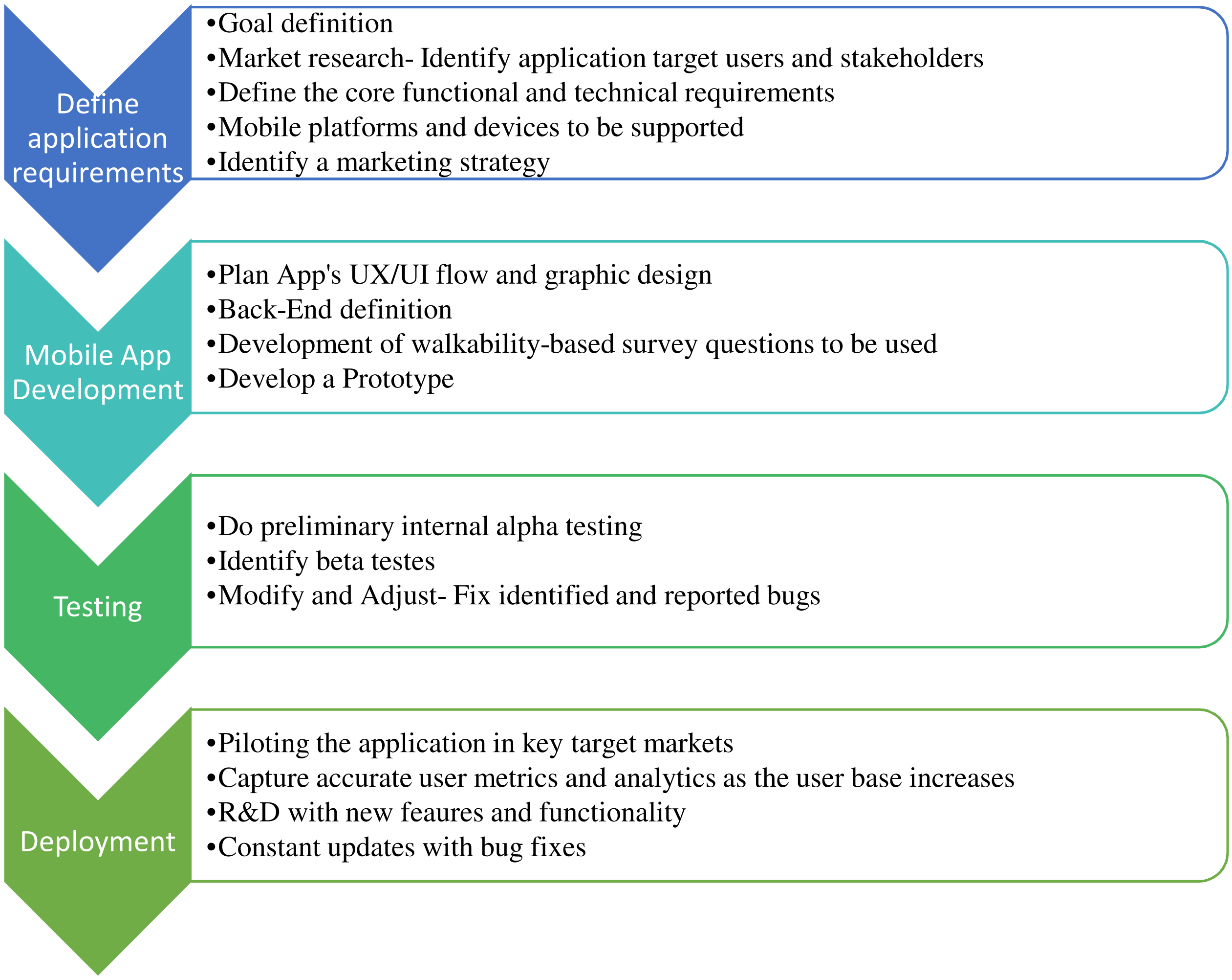


Fig. 2.2: The application design process

Application testing phases

Beyond ensuring that all technical aspects of the application are functioning correctly, and the application Cloud back-end services scale-up properly in terms of responsiveness and time-lags while accessing data records with increasing user numbers, the application will continually be updated and improved based on the feedback from the alpha and beta testing. This will continue until all the identified kinks are remedied for the application to be ready for wide-scale public release.

Fig. 2.3: Mobile application testing phases

The application will go through five phases of development before it is ready for wide-scale public use. The first three phases; User testing, Integration testing, and System testing comprise initial internal tests performed by the coding and development team in coming up with the basics of the application. Once the development strategy is in place, a great mobile experience that enhances productivity will be created by standardising the internal development process.

The alpha and beta testing are forms of user acceptance testing that will involve more people than just the coders and developer. The results of these user acceptance testing stages will be outlined and discussed in subsequent sections of this report.

i. Unit testing
ii. Integration testing — Performed at the system development level
iii. System testing
iv. Alpha testing- This phase tests new functionality on a demo project corresponding library. It is done to identify all possible bugs by simulating real users by using BlackBox and Whitebox techniques to perform the tasks that a typical user might perform. In Blackbox techniques, the testing is conducted from the viewpoint of the end-user and the tester knows only about the inputs and the expected outputs of the application and not the internal codes and structure of the program. Conversely, in Whitebox techniques, the internal codes and structure of the software are known to the tester, with the view to strengthening the security and improving the design and usability of the application. It is conducted in a closed environment and testers are typically the design team members. If the new functionality works, it is then merged to the Beta channel (Shrivastava, 2015).
v. Beta testing- The tester needs to verify that every feature (old and new) is working. It is performed by "the actual users" of the application in the real world like some external User Acceptance Testing. The beta version of the application is released to a limited number of end-users for their feedback on the product quality to minimise product failure risks through customer validation. After the beta testing phase is complete, and all test results prove satisfactory, the corresponding testing issues may be closed one-by-one. With each closed testing issue, the functionality moves to the production channel (Shrivastava, 2015).
vi. Production- This channel means that the application is completely ready for use on any of the supported phones and is then released to the public via the various application stores such as Google's Play Store and Apple Store (Shrivastava, 2015).

The process can, therefore, be simplified as follows: The application development process starts by listing the required features, the application scope, and the best tools for developing the application. The User interface UIX is determined next by opting for a design that delivers the best user experience. Each functionality is coded and deployed one by one and tested individually then collectively with other functionalities. Back-end processes are implemented to support the application. Through the user quality testing, bugs are identified, and the necessary changes are made i.e.

- Requirements and specifications Analysis;
- UI and graphical user interface Design: Application of User Experience Design; Usability planning;
- Database design and implementation: Server deployment (Back-end and front-end construction); Pilot application deployment;
- Verification: Validation and certification, Unit tests, and error corrections;
- Maintenance.

3. LITERATURE REVIEW

3.1. Introduction

A literature review of the recent and historically relevant literature on the topic of walkability audits demonstrates that past studies are primarily focused on the development of transport-based mobile phone applications with basic features and limited functionality, which do not factor in multiple sensory modalities for enhanced visual appeal, ease of use, and aesthetics. A walkability audit is an unbiased evaluation of the walking environment to identify concerns for pedestrians (and cyclists) related to the safety, access, comfort, and convenience of the environment. Besides identifying problem areas, an audit can be used to identify potential solutions and alternatives such as engineering treatments, policy changes, or education and enforcement measures. These walking suitability assessments allow for both quantitative and qualitative data evaluation by providing systematic data allowing for the identification of streets in need of design improvements. They can be conducted before, during, or after the infrastructure provision.

3.2. Walkability

3.2.1. What is Walkability

Walkability is simply a measure of how practical and pleasant an area is to walk. It is a more recent addition to transportation planning processes, but it is still accorded far less importance, evidenced by the limited investment in research, planning, and design, as compared to motorised transport. To further illustrate this point, the 2004 AASHTO Green Book allocates only 16 of the 867 pages to the geometric design of pedestrian facilities, and in the rest, it recommends that the streets in which pedestrians operate should be designed according to their vehicular function (Hutabarat, 2009).

Often, vehicle functions take precedence over pedestrian safety and requirements, and even when spaces are explicitly designed for pedestrians, there are conflicts between different performance measures used to evaluate these facilities (Hutabarat, 2009). According to the United Nations (UN), for a city to be deemed to be well planned, at least 30-35% of its land must be dedicated to streets to get the advantages of connectivity. This would also allow for greater accessibility as it would allow for more than one route to a destination which has positive benefits to the congestion levels. Correspondingly, when traffic volumes are low, the quality of walking and cycling increases because speed relates to safety and noise. Pedestrians are more comfortable to walk or sit where vehicle speeds are low, usually about 20kph (Kim & Dumitrescu, 2010)

A study by professor Karl Kim (PPS, 2011), on a busy area of the city of Honolulu in Hawaii, found that up to 33% of the variation in pedestrian volumes could be attributed to environmental quality factors such as sanitation and hygiene, noise levels, odours, and the availability of pedestrian-friendly amenities such as ramps, benches, shelters, and paving. The study found that the proximity to transit raised the likelihood and frequency that people walked, and that street network characteristics such as connectivity, configuration, and compactness, influenced the levels of driving. In other words, the denser, and more gridded the street network, the less the vehicle miles travelled (PPS, 2011).

According to Jeff Speck (Speck, 2012), for people to opt to walk a particular path, four factors had to be satisfied; it had to be safe, comfortable, useful, and interesting. These factors are similar to those proposed by other authors, as will be outlined later. He also argues that the 'fabric' of a city in terms of the variety of buildings, frontages, and open spaces, is crucial for walkability (Speck, 2012). Unlike traditional European cities which were built with walking in mind and hence had good 'fabrics', modern cities were instead built with the automobile in mind and consequently, have the challenge of retrofitting walking infrastructure. Speck provides the example of Rome in which, despite the streets being worn out, having uneven pavements, missing sidewalks, crossings, and unavailable disabled ramps, the city still attracts pedestrians in large numbers. This, he contends, is because of the city's excellent 'fabric'. Paris, for example, was initially designed for walking, but motor vehicles have taken over with time. A walkable city can, therefore, be deemed a city in which a car is viewed as an optional instrument for mobility rather than a necessity.

Speck (Speck, 2012), who is a proponent of 'New Urbanism', claims that historically, there have only been two ways that have been extensively tested, to build communities. The first is the traditional neighbourhood, which is defined as being compact and is diverse in terms of places to live, work, shop, recreate and get educated, all within walking distances. There are numerous small streets, each of which is easy to walk on comfortably. The second way is suburban sprawl, which emerged after the end of World War II. It is neither compact, diverse, nor walkable because most of the streets do not connect and those that do become overburdened and uncomfortable. The various land uses are separated from each other, such that there are places to go if you want to shop, work, school, recreate, and live. These places remain entirely separate from each other.

His conclusion was that to design a walkable city, one should not begin the design with the sprawl model but instead use the urban model. It is possible to have an entirely walkable neighbourhood without transit, but impossible to have an entirely walkable city without it, because if one does not have access to the entire city as a pedestrian, then one opts to get a car. Moreover, by getting a car, the city begins to reshape around one's needs, such that the streets get wider, and parking lots get bigger, thereafter, the city is no longer a walkable city (Speck, 2012). Walkability should also be built around transit stations because every trip begins and ends with a walk. By the same token, he argues that the concept of induced demand applies both to highways as to city streets.

Walkability is not a luxury rather a necessity for equity and sustainability. This necessity becomes more pronounced when considering that according to the United Nations (UN), by 2050, two-thirds of the world's population will live in cities (United Nations, 2016). To correct and prevent the perpetuation of unsustainable and inequitable urban planning practices, and to cater for the mobility needs of this ballooning population, attention will need to be placed on the promotion of sustainable transportation and urban spaces planning practices. A survey conducted by the American National Association of Realtors in Portland State revealed that 83% of millennials (those born between 1977-1995) liked walking compared to 71% driving, and half of them preferred living within easy walking distance to other places (NAR, 2017). An equal number (51%), preferred living in attached housing where they could walk to shops and have shorter commutes, and 40% used public transport. 32% of them walked to work or school, and 62% walked for errands (NAR, 2017).

These findings seem to suggest that unlike previous generations of adults, the younger generations exhibit different tastes and preferences in meeting their mobility needs. Another study in the USA (Schmitt, 2018), found that there was a generational divide when it came to cars and driving, and the unavailability of alternate forms of mobility. More than two out of three Baby Boomers (born 1946-1964) said that their car was worth more than the cost of maintenance whilst only half of Millennials said the same. 59% of the Millennials compared to 45% of Baby Boomers said they would "rather spend time doing more productive tasks than driving", and one in three Millennials said the amount of time they spend in their car is "very frustrating." 48% of Millennials, 61% of Baby Boomers and 51% of Gen Xers (born 1965-1976) said they "enjoy most of the time spent driving." (Schmitt, 2018).

These differences should be factored into how infrastructure, land use, and urban planning is performed, and this could have considerable impacts and opportunities for equity and sustainability. Only 13% of respondents said that they could "live without having access to a vehicle" and 40% of everyone from all generations had never tried an alternative to driving, including transit, cycling or ride-hailing apps (Schmitt, 2018). Due to the vivid untapped demand illustrated in the results of these studies, there is a clear need to cater to and promote walkability as a measure of promoting more sustainable commuting practices, particularly among the younger generations.

3.2.2. Why Walkability is important

Health and wellbeing

When advocating for walkability, it is essential to use public health arguments including those linked to obesity, healthcare costs, and the death rates from vehicular accidents and air pollution (Speck, 2012). Walking has the benefit of leading to reduced mortality and morbidity (illnesses or disease burden). According to the results of a study in Montreal, Canada, (Ghenadenik et al., 2018), urban design is a factor in the development of childhood obesity. The data for the study was collected two years apart (2005 and 2008) from a sample of 630 children of ages 8-19 years, with a family history of obesity. The study participants resided at their current residential addresses for the entire duration of the study (Ghenadenik et al., 2018).

Follow up was done in 2008 and 2011. The study found that children who resided in easily walkable neighbourhoods had a smaller waist circumference and lower Body Mass Indexes (BMI) implying that infrastructure designed to encourage walking, had a proven contribution to the improvement of child health. The level of walkability was assessed based on the availability of various built environment features, traffic calming features, pedestrian aids, physical activity facilities, and the number of convenience and fast food stores in the area. The data analysis, using 391 of the children, was done using multivariate regression models (Ghenadenik et al., 2018).

This study was particularly important considering that presently in the United States, a third of children and two-thirds of adults are either obese or overweight, and the number is steadily rising. Obesity is linked to other major health issues including cardiovascular disease, type 2 diabetes (37% of American adults are prediabetic, 8% have type 2 diabetes and 3% have type 2 diabetes but are undiagnosed), sleep apnoea, depression, and high blood pressure. It is approximated by the Institute of Medicine (IOM) that about $90.2 billion is the cost of obesity-related illness, 21% of annual medical spending, and $4.3 billion is the annual losses to businesses because of obesity-related job absenteeism in the US. Compared to 1977, when 4.1% of Americans walked to work, only 2.8% do so as of 2008, and only 19% get the daily-recommended amount of physical activity. In 1977, 20.2% of school-aged children walked to school, but as of 2001, the number had dropped to 12.5% (Ghenadenik et al., 2018).

Daily calorie consumption over the past 40 years has been on a steady rise since 1971-1974 whereby it was 1,996 calories a day, to the 2,234 calories a day in 2005-2008, with 30-40% of children and adolescents consuming fast foods on every given day. The crisis is compounded by the fact that the percentage of high schoolers attending daily physical education classes has dropped from 41.6% in 1991 to 33.3% in 2009. Half of these children's waking hours are spent in school, and a quarter of an employed adult's life is spent in the workplace. A fifth of the weight gain in the US between 1977 and 2007 is attributed to sugar-sweetened beverages (IOM, 2012). Of the 7.5 hours of media consumed each day by older children and adolescents, 87% of food and beverage ads on television are for products high in saturated fat, sugar or sodium.

The IOM recently recommended five measures, used in conjunction with each other, to reverse obesity trends; Physical activity should be integrated in daily activities, focus be placed on schools to promote health, marketing of healthier foods, increase the availability of healthier food options, and make better use of employers and health care professionals in this effort (IOM, 2012).

According to a 2017 study (Simons et al., 2018), children living in neighbourhoods with low walkability are at increased risk of asthma. The study evaluated a sample size of 326,383 Toronto children born between 1997 and 2003 and followed them up to the age of 8 to 15 years. The researchers found that 21 % of the children developed incident asthma and there was an increased incidence of asthma among neighbourhoods with low walkability (hazard ratio, 1.11). Low walkability in a given year of a child's life was associated with higher odds of ongoing asthma in the same year (odds ratio, 1.12). Home neighbourhood walkability quintile was measured using a validated Walkability Index with four dimensions: dwelling density, population density, street connectivity, and access to retail and services (Simons et al., 2018).

Walking regularly could reduce the risk of heart disease and stroke by 35%, type 2 diabetes by 50%, Alzheimer's disease by 45%, and some cancers by 20-50%. Experts recommend at least 150 minutes of physical activity per week. Research has shown that public transport users take 30% more steps per day than private vehicle users and people who reside in areas with sidewalks and other walkability promoting facilities, are 47% more likely to be active at least 30 minutes a day and 50% more likely to meet physical activity guidelines (Wilson, 2012).

Those living in mixed-use neighbourhoods with work, play, and shopping nearby, are 33% more likely to meet the physical activity guidelines.

On top of providing aerobic exercise, walking has the added benefit of facilitating socialisation and could lower stress levels as people experience the psychological and calming effects of being outdoors in nature. Walking is also the quietest form of transport. People's health and wellbeing influence their productivity because of reduced absenteeism, and for this reason, there is a case to be made for governments and employers to promote walking.

Socioeconomic factors

Walkability correlates with added economic benefits, cost savings both for individuals and governments, improved accessibility, improved liveability and social interaction, and less crime with more people walking and watching over neighbourhoods. The cost of implementing walking infrastructure and facilities is significantly less than for motorised transport because they take up less space. The cost-benefit analysis favours a shift towards promoting walkability. As has been shown by the example of Greece, having more sidewalks and increased walkability can promote tourism and increase property values which have economic benefits. The demand for housing in easily walkable neighbourhoods has ballooned in recent years and will continue to grow, increasing property values. The changing city landscape and street configuration would lead to cleaner, less congested cities and promote equity.

To calculate the cost savings from reduced congestion, the additional journey cost incurred when travelling in congested conditions must be compared with free-flow conditions. Congestion costs are therefore a factor of both the volume of vehicles on the road and average traffic speeds and having fewer road users will lead to increased traffic speeds and reduced volumes resulting in congestion cost savings. Vehicle costs savings, on the contrary, occur from the savings for vehicle operating costs which include fuel, tyre repair, parking costs, maintenance and depreciation (PriceWatehouseCoopers, 2009).

Walkable areas gain just from their proximity to other walkable areas such that typically, walkable neighbourhoods in metropolitan Washington that cluster forming walkable districts, exhibit higher rentals and property values than separate, unconnected walkable areas. Inhabitants of more walkable areas have greater transit access, higher housing costs, and lower transport costs. These Washington residents generally spent 30% of their income on housing and 12% on transport. Comparatively, inhabitants of areas with scarcer environmental features that encourage walkability spent 18% on housing and 15% on transport. They were also generally less affluent and had less academic achievement and education than areas with more walkability. Places with greater walkability facilities and provisions had also become more gentrified over the past decade (Alfonzo & Leinberger, 2012).

Today, companies are preferring and opting for walkable central locations and studies have shown that it can lead to up to a 60% increase in productivity and creativity. In terms of productivity, more physically active and mentally healthier employees are less likely to take time off. Improved walkability has also been proven to increase local retail spend, enhance the value of local services and create more jobs. Footfall and trading have been shown to increase by 40% by improving the walkability of places and pedestrians have been found to spend, on average, 65% more than drivers (Schofield, 2016).

Safety and Environmental factors

Every mile walked instead of driven cuts out 0.2 kg of CO_2, and if everyone in the US walked one day per week instead of driving, traffic would reduce by at least 10%. One additional walking Km trip replaces 0.583 car Km trips and 0.193 bus, train and other forms of motorised transport trips (Bureau of Transport and Regional Economics. (2007). Walking produces virtually no air pollution, apart from the minuscule increase in CO_2 emissions associated with an increase in metabolic rate. The benefits of less pollution of carbon compounds include less smog, less pollution and contribution to climate change, improved health conditions and quality of life.

In comparison, vehicles are significant contributors to air pollutants including oxides of nitrogen (NOx), carbon monoxide (CO) and hydrocarbons. For example, in Australia, cars produce half the NOx, CO and hydrocarbons emissions each year.

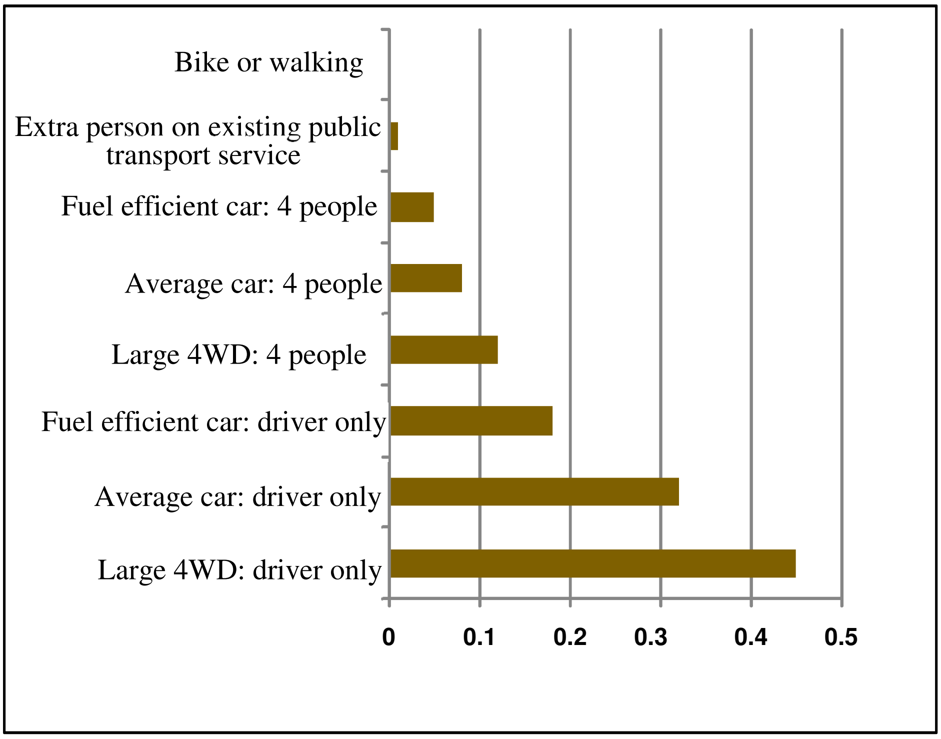


Fig. 3.1: Transport mode emissions

(Adapted from Bureau of Transport and Regional Economics, 2007)

According to the World Health Organization (WHO), compared to other road users, pedestrians are the most vulnerable accounting for 22 % of the 1.25 million road fatalities annually in the world, 90% of which occur in low and middle-income nations, which is also the top killer of people in the age group 15-29 (Scruggs, 2018). Research in the US has shown that medians, speed bumps and other traffic calming activities can reduce the number of automobile crashes with pedestrians by up to 15% overall; 10% on main roads and 25% on residential streets (Spoon, 2016).

For example, by making the streets more walkable, in Auckland, New Zealand, a city that is notoriously car-centric, walking levels increased by 54%, retail spending by 47%, traffic fell by 25%, and 80% of people said they felt safer than before the walkability improvement (Laker, 2018).

Changes in travel times

In urban environments characterised by short-distance travel, walking is often faster than other modes such as cars or trains. This is much more pronounced in developing countries that experience severe traffic congestion in urban areas making it quick to walk to destinations rather than sit in traffic, particularly at peak times. According to the Australian Transport Council stated preference research, people are willing to trade off 1.15 – 2.00 minutes of additional time spent travelling on rail to avoid 1 minute of walking access time; and the willingness to trade-off is higher in crowded conditions or when the walk is part of an interchange. Figure 3.2 illustrates that the target market for diverting trips from private vehicles to walking is for distances less than 1km when the time differential between car and walking is lowest (Australian Transport Council, 2006).

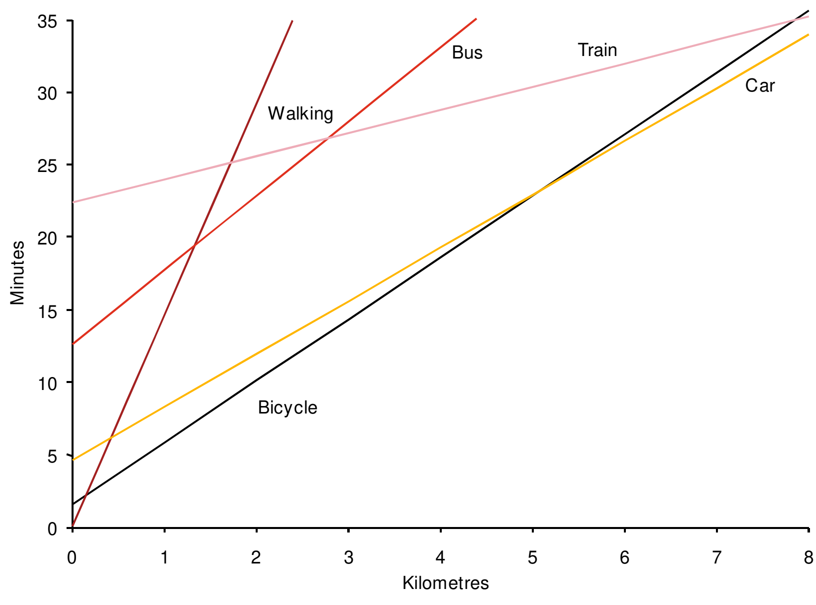


Fig. 3.2: Urban environments comparative journey speeds

(Adapted from Bureau of Transport and Regional Economics, Australia, 2007)

Equity and sustainability

The 'New Urban Agenda' of October 2016 as part of the UN-Habitat III declaration (United Nations, 2016), set out a new global standard for sustainable urban development for the next 20 years, to facilitate the planning, management, and liveability of cities, homes, and neighbourhoods of the future. It recognised the spatial, social, cultural and economic inequalities that were present in cities. It was developed as a roadmap for the development of cities that were engines of prosperity and centres of cultural and social well-being as much as also protecting the environment.

As part of its agenda, is the achievement of the Sustainable Development Goals and the tackling of climate change. Its commitments include the promotion of measures that support cleaner cities, taking actions to address climate change by reducing greenhouse gas emissions, improving connectivity and support innovative and green initiatives, and the promotion of safe, accessible, and green public spaces (United Nations, 2016). Walkability promotion plays a key role in the achievement of these goals. When implemented, these initiatives result in better outcomes for land use patterns, inequality reduction, and improvements in urban form, increasing compactness and walkability. By promoting walkability, people walk more and thereby use motor vehicles less, reducing their GHG emissions and tackling climate change and its related risks, for cleaner and greener cities. Walkability promotes accessibility and connectivity between destinations and goes a long way in making cities inclusive, safe, resilient, and sustainable. By ensuring access to the public sphere, equity and social justice can also be promoted.

3.2.3. The state of Walkability in the Developing Country context

Developing countries that illustrate the everyday need to cater to and promote walkability are the cities of Kampala (Uganda) and Nairobi (Kenya). Kampala is the capital and largest city of the Republic of Uganda situated in East Africa and located on the northern shores of Lake Victoria. It has a population of 1.6 million, 60% of whom live in slums (UN-Habitat, 2007), and developed mostly unplanned, creating a mismatch between employment, housing, and services. The slums grew organically by responding to the needs of the residents, without government planning because they are not part of the formal city planning processes since most of the inhabitants are illegal squatters on the lands and are always at the risk of eviction. Uganda has the highest population growth rate in the world and is set to triple its population of 37 million by 2050.

Fig. 3.3: Slums and informal settlements in Kampala

(Help for Uganda, 2017)

Like cities in many other developing countries, Kampala central business district (CBD) is the sole centre of economic activity, and therefore travel patterns are oriented towards the city centre. There are three main modes of transport for the average Kampala resident; walking, motorcycles (colloquially referred to as *bodaboda*), and 15-seater minibus taxi. Walking is the dominant means of transport and the easiest way to reach destinations because of the narrow streets. Pedestrians are captive rather than choice travellers. Desire paths which are paths that do not follow a regular grid system, dot the city landscape as people look for the fastest routes to their destinations. These desire paths allow for one to walk just about anywhere in the city. *Bodabodas* are typically hired to ferry goods, and people over short distances (from about 800 m distances or over 8-minute walk), while minibus taxis are used for longer distances, typically distances over 3Km.

There are no formal designated stops for the *bodabodas* and minibus taxis which can be hailed down at any points and drop off passengers at any points of their choosing. Walking in Kampala is a challenge for most people, particularly the city centre that is very chaotic, crowded, and a beehive of activity. Transport and commerce occupy and share the same space. Walking is the primary mode of transport for about 46% of the city's population. This mix of traffic creates a vibrant mixed-use space such that the minibus taxis move people to and from the centre of Kampala then *bodabodas* pick them up from the tarmac roads and take them to the fringe areas along unpaved roads to their neighbourhoods. They then walk to their houses.

Fig. 3.4: Crowded streets of Kampala

(Source: alamy.com)

The narrow streets are unable to cater for the high demand for transport, resulting in severe congestion. The paths in Kampala's slums get denser and smaller the further one goes from the city centre. The imbalance between the increase in demand for travel and the supply of infrastructure has led to excessive congestion levels. The poor state of transportation is exuberated by the ballooning unregulated paratransit industry that contributes to the already chocking levels of congestion and accidents due to their manner of operating. The government's focus has primarily been on motorised transport, with little attention paid to the walkability of the city. To further illustrate the level of neglect for non-motorised transport, in Uganda, only 1% of the population own private cars but receive all the priority (JIKA, 2010). The fragmentation of land use and transport planning has resulted in sprawling and unsustainable transport solutions that are inefficient and unreliable.

Security, particularly at night, is typically the most pressing concern for residents and visitors for most routes. Visitors are often advised to ask locals which roads and routes are safe to get to their destinations, and which ones to altogether avoid either due to crime or due to the state of the walking infrastructure. Most roads in the city including major thoroughfares are unpaved, and the sidewalks are often non-existent. Where sidewalks are available, there are often blocked by *bodaboda* (motorcycle taxi) riders who opt to utilise them or hawkers and street vendors that set up on the sidewalks. 60% of the streets of Kampala's city road network have no sidewalks (JIKA, 2010). The quality of the sidewalks is often poor, characterised by manholes with no covers, potholes and bumps, and missing pavements. There are also no exclusive lanes for cyclists who are forced to utilise the same space with motorists and pedestrians (where footpaths are available). Parking facilities are also unavailable for cyclists and insufficient parking for vehicles.

Because of the poor state of most roads, rainy weather makes it almost impossible to walk because of the mud and puddles of water occasioned by poor drainage. The poor drainage leads to the development of potholes, which become hazardous when the depth of potholes is indeterminable after heavy rains or zebra crossings not being visible.

Fig. 3.5a: Poorly-drained street with no walkability provision in Kampala

Figure 3.5b: Well-drained street with walkability provision in Kampala

Neighbouring Kenya is also characterised by unplanned development, urban poverty, massive unemployment, and environmental degradation. The unchecked dumping of garbage by the residents has severely affected the natural environment, drainage, and the condition of the road reserves.

Fig. 3.6: Uncontrolled dumping of waste and unmaintained road shoulders in Nairobi

Street lighting is either faulty or non-existent on most roads, and road signage is generally poor. Recently, both Nairobi and Kampala have often been at the centre of street protests and demonstrations that have attracted the attention of state police who lobby teargas canisters in the general direction of the protesters. Innocent passers-by have occasionally been caught in the middle of such confrontations. Paratransit minibus transit operators (*matatus*) have an aggressive driving style that increases the unsafety for pedestrians who must make way for the minibuses and *bodabodas* that are very manoeuvrable even on footpaths and zebra crossings, as well as the safety risk to other road users. They typically use roads shoulders to overtake other vehicles during traffic jams. 6% of all fatalities and 5% of all severe injuries in the Kampala are from cyclists who account for only 2% of the vehicles on the road (JIKA, 2010).

It is worse for pedestrians because, in 2010, half of all fatalities and 40% of all severe injuries in Kampala were from pedestrians. On the bright side, walking in most of these cities, indeed in Nairobi and Kampala, allows one to come across places they would never see in a vehicle. There are many bars and local cafes along the way, and views. The countryside is the complete opposite because there are open picturesque views and no traffic jams like in the cities. This portrays the typical case for most developing countries particularly those in Africa and informs the need for these new and crowdsourced technological innovations that attempt to provide an answer to contemporary walkability policy and concept questions.

The above narrative vividly illustrates the potential for Sub-Saharan African cities to become more walkable. In the final analysis, the manner with which sustainable urban transport is introduced should be tailored to the local circumstances and preferences and not directly copying or retrofitting what has been done in other global cities. In other words, a sustainable urban transport system should serve pedestrians and not vehicles. Informal settlements will continue to grow as the population increases in developing countries. They will have to be connected to the formal city and improved to allow a higher quality of life for their inhabitants.

In the case of developing nations, a quick and inexpensive way to redesign the existing roadways and convert streets into complete streets would be to make use of bollards, planters or even parked cars to create dedicated space for walking. This is to attain a suitable balance between urban development, transport, and liveability. The urban space would need to be planned rather than haphazard developments that lead to buildings blocking pedestrian flow instead of facilitating it.

3.2.4. Quantifying Walkability

There are two broad approaches to quantifying walkability. Objective measurement is independent of the observer and involves an impartial, unbiased and unprejudiced measurement that it is not subject to personal opinion or individualised interpretation of results. Subjective measurement is influenced by the observer's judgement and is often open to interpretation and counter opinions. These two measures can be seen as a continuum between highly subjective to highly objective and can be used to complement each other. Measurements can be made more objective by making use of checklists, rating scales and indices or some form of auditing tool.

Fig. 3.7: Subjective and Objective performance measurement continuum

Various pedestrian performance metrics have been suggested over the years each with their different definitions of how to measure walkability. Flow capacity has historically been the go-to approach to measure the level of walkability and is the method used in the Transportation Research Board's (TRB) Highway Capacity Manual (HCM), first published in 1950, in the

United States, as a transportation planning guideline. It contends that pedestrian space is best when pedestrians can move in an unimpeded manner with as much free space as possible. The Manual was updated in the year 2000, to correct a recurring criticism that it showed bias towards motorised and road-based transportation modes and it was thereby expanded to include NMT.

In terms of walkability, several quantitative variables and associated descriptions were used to grade pedestrian LOS (Level of Service) just as the Manual had done for highways over the years. The parameters considered were limited and failed to account for other variables that may also be important for pedestrians. The parameters included were the flow rate of pedestrians, the amount of personal space that each pedestrian has within the sidewalk area, the speed of pedestrian flow, and the ratio of sidewalk volume to capacity.

The Highway Capacity Manual promotes maintaining space at all times between pedestrians themselves and shop frontages, to prevent them from bumping into walls and each other, which is classified as a conflict. An empty sidewalk in an industrial super-block or a dark city alley would be ranked better than a busy pedestrian sidewalk in an urban setting (Hutabarat, 2009). It also did not consider contextual factors such as the vitality, land-use context, amenities, street connectivity, and building form. Vehicular LOS grades from A-F represent subsequent levels at which motorists can undertake, more comfortably, manoeuvres at a higher speed. Pedestrian LOS grades from A–F then again, are not as pedestrian-focussed such that they erroneously provide that sidewalk capacity and unimpeded movement are the most critical factors, and therefore the best pedestrian environments are those with the fewest pedestrians. In 2003, the City of Kansas further defined the HCM's pedestrian LOS requirements for directness and continuity, allowing planners to introduce an understanding of the relationship between pedestrian behaviour and land-use context, based on the following;

- Pedestrian zones and pedestrian streets;
- Routes to/from transit;
- Neighbourhood activity centres and corridors;
- Schools and parks;
- Mixed-use and transportation centres or transit zones;
- All other areas within the city.

(Hutabarat, 2009)

The World Bank developed the Global Walkability Index (GWI), which assessed 10 "universally applicable" multimodal measures of walkability including: crossing safety; maintenance and cleanliness; motorist behaviour; modal conflict; security from crime; obstructions; availability of street crossings; pedestrian amenities, street lighting; disability infrastructure and sidewalk width; and volume of use. The GWI, nevertheless, omitted land-use variables and their effects on the convenience, directness, and connectivity of the pedestrian network, because the index only targeted those aspects of walkability that could be improved in the short and medium terms, as opposed to those that may only be affected in the long term (Kim et al., 2010). These multimodal measures of walkability, compared to flow capacity metrics, provide a more nuanced understanding of pedestrian activity and its relationship to land uses and the physical environment but could undermine operational factors such as traffic and pedestrian volumes.

In 2000, Jaskiewicz (Hutabarat, 2009), an urban designer, translated design ideals into LOS grades that could more easily be evaluated quantitatively, by compiling qualitative pedestrian LOS factors to supplement the HCM flow capacity approach. He focused on factors influencing the aesthetic appeal of pedestrian environments, including buffering between pedestrians and traffic; complexity of spaces and paths; presence of overhangs and varied rooflines; building articulation and variation; street definition or enclosure; presence of shade trees and lighting; the physical condition of sidewalks; and the transparency of the transitional zone. Each item was graded on a scale of 1 to 5, by a panel of experienced urban designers, and scaled to a scale from A-F. This method, however, came under significant criticism for being too subjective and not scientifically derived (Hutabarat, 2009).

A Canadian study quantified walkability based on three factors; density, diversity, and design. Density was quantified as the residential population density and job density while Diversity was quantified as the percentage of residents within walking distance of defined diverse uses (DUs) that provide a measure of mixed-used development. The calculation of these two parameters could then be determined using the ArcGIS software geocoding tools, ModelBuilder 9.3, and the Network Analyst 9.3 extension. Design, on the other hand, was quantified as trail availability per 1,000 residents, bicycle path availability per 100 residents, and the number of intersections per square kilometre (Rattan, A et al., 2012).

The field of public health and active living has also made contributions to the metrics for walkability and pedestrian quality as a basis for addressing lifestyle diseases. Research by Rosenblatt Naderi (Naderi & Raman, 2005) showed that physical factors (such as sidewalk width), are much more critical for commuters than for health walkers. In contrast, aesthetic and phenomenological factors were more significant to those walking for health reasons. A study to determine the level of physical activity of adults aged over 85 years in the United Kingdom using 484 participants, was able to obtain objective measures of rest/activity, activity intensity, and type by having 337 of the participants wear triaxial, raw accelerometers on their wrists over a 5–7-day period. This was compared with results collected from a self-reported subjective physical activity questionnaire or walking audit. The results from the two data collection methods showed significant variance, and after statistical analysis and normality tests, the objective measurement was deemed the most accurate and valid result (Innerd et al., 2015). Another study in 2009 by Lin and Moudon that compared the strength of association of subjective and objective measures of the environment with walking found that objective measures of the built environment had stronger associations with walking than subjective measures (Lin, L & Moudon, A, 2010).

Three published studies found that, contrary to the conventional wisdom that the number of collisions varies directly with the amount of walking and cycling, the likelihood that a pedestrian or cyclist has an accident with a motorist varies inversely with the amount of walking or cycling. This result implies that motorists adjust their behaviour in the presence of pedestrians and cyclists. There is, therefore, the reduced likelihood of vehicular accidents with pedestrians and cyclists if more people walk or cycle, therefore, by improving walkability, safety for pedestrians and cyclists will improve (Jacobsen, 2003).

A popular online tool called *WalkScore* (Walkscore, 2019), allows for the ranking of American, Canadian, and Australian cities, on a scale of 1-100, based on how walkable they are as per proximity to key destinations. The algorithm awards maximum points to amenities within 5 minutes' walk and a decay function assigns points for amenities up to 30 minutes away. In their latest ranking of 2017, New York City, San Francisco, and Boston were the most walkable cities in the US, Vancouver, Toronto and Montreal in Canada, and Sydney, Melbourne, and Adelaide in Australia. The tool's creators are currently piloting a 'street smart' version of the tool, that uses actual street distance to destinations instead of 'as the crow flies' distances. Its limitation is that the score is still based on mapped street routes and does not account for any urban design or environmental factors that might influence walkability, including the presence or absence of sidewalks (Laker, 2017).

A walkability application called *You can choose* (Google Play Store, 2019) is simply a mobile phone application that allows for the collection of data on the state of walkability. It was developed in Asia with data from 130 cities. It ranks streets on an index (0-100 scale) based on the cumulative ratings of people, based on the merits of the street in terms of aspects such as infrastructure provision, state of infrastructure, and security. Similarly, a web app called *Walkonomics* (Google Play Store, 2019) combines open data and crowdsourcing to rate and review the walkability of each street. As of 2011, it had ratings for every street in New York and England (over 600,000 streets). The University of California, Berkeley is establishing a composite walkability index that integrates a pedestrian perception survey and detailed 'objective' measurement of street urban design factors emphasising the value of user's perceptions of safety, security and comfort, in their decision to walk. Michael Lowrey (PPS, 2011) assessed street "completeness" based on context and public input, using audits for transit users, pedestrians, cyclists, and automobiles, allowing communities to rate how much a street currently is, and how it should be oriented toward various modes of travel (PPS, 2011).

Joe Chestnut (ITDP, 2018), from The Institute of Transportation and Development Policy, designed a tool, *Pedestrians first,* to measure walkability by measuring features that promote walkability in urban environments. The tool assesses based on infrastructure availability, activity, and priority given to different modes of transport. The tool does this using eleven indicators for walkability as follows;

i. Walkways- Their availability and condition in terms of completeness, continuity, safety, i.e. protection from vehicles, and universal accessibility.
ii. Driveway density- The ideal case is one that improves safety and comfort by having an urban walking environment with fewer locations where pedestrian must cross the path of vehicles.
iii. Small blocks- Streets and buildings designed to have small blocks reduce trip lengths, make walking more convenient, and reduces the need to make a dangerous mid-block crossing.
iv. Crosswalks- To facilitate universal access and safe connection of the walkway network with vehicle traffic.

v. Access to Local Services- Basic services within easy walking distance.
vi. Roadway area- The portion of the roadway reserved for motor vehicles compared with the allocated space for NMT.
vii. Complementary uses- Improved accessibility by having a mix of uses, thereby reducing the distance between homes and services and shorter trips increase the likelihood that these trips would be taken on foot.
viii. Prioritised Connectivity- Walking is given priority over motor vehicles at connections, improving the convenience of walking.
ix. Visually Active Frontage- Appealing frontages promote safety through informal observation and surveillance by people inside buildings commonly referred to as "eyes on the street".
x. Physically Permeable Frontage- There are fewer zones of inactivity in sidewalks with continuous ground-floor activity, improving safety.
xi. Shade and shelter- For improved comfort and accessibility by offering protection from the sun, rain, dust, and other elements.

(ITDP, 2018)

There is not one perfect measure of walkability instead because of the uniqueness of people and places; the tools developed will have to adapt and evolve to specific needs and uses. The New Urban Agenda offers a couple of metrics that are paired with their principles, for the quantifying of walkability. Evaluating walkability could be as simple as looking at mode share or conducting surveys to understand user satisfaction with sidewalks.

It emerges from the literature that the factors affecting people's decision to walk or make use of other mobility options are; uses & activities, access & linkages, comfort & image, and sociability (whether there are other people around). There has been an inclination towards lower pedestrian volumes – and, by inference, lower density land-use contexts. This is contrary to urbanist values for both accessibility and security, as well as recent literature promoting the idea of "safety in numbers" for NMT (Hutabarat, 2009).

3.2.5. Measures to improve Walkability

A number of policy and engineering interventions are recommended to promote and enable higher levels of walkability. To promote walkability, the necessary enabling environment including safety, comfort and the supporting infrastructure must be provided including, well-maintained sidewalks, street lighting, shelter from adverse weather, benches, and water fountains. Various pedestrian safety factors should be implemented such as wider lanes, one-way streets, and curbside parking which has the added advantage of providing a buffer between pedestrians and traffic.

Because of the effect of induced and latent demand, there is a realisation that increasing road space will only lead to more vehicles on the roads. Traffic engineers and urban designers should move away from the traditional car-first design approach whereby streets are seen to be conveyances for motor vehicles that has led to congestion on most urban roads. Making driving inconvenient, difficult, and expensive would encourage walking and other NMT activities. Ideally, Transport Demand Management (TDM) is more applicable in less developed countries where most inhabitants already rely on walking and mass transit. These countries have the potential to leapfrog an era of car-dominated development and evade its negative impacts.

Research (Huang, 2016), (Speck, 2012), has shown that high-density mix-use neighbourhoods with closely located land uses within walkable distances, exhibit significantly more walking. In such instances, people are more likely to opt to walk to their destinations. Standardised metrics should be produced that provide guidelines for walkability infrastructure. For example, a metric stipulating 10 km per km squared for pathway density and connectivity is ideal, but a design metric like sidewalk width might require more flexibility because some areas work well with a sidewalk width of 2 metres, but some might require 3 meters (Huang, 2016). Reducing the availability of low-cost parking would discourage motor vehicle use and inspire more people to use alternative NMT means such as walking. Park and ride facilities can alternatively be provided at transit stations.

The environment around the walking path should be aesthetically attractive in terms of having sufficient trees and vegetation, which have the added benefit of providing natural cooling, reduced emissions, and energy demand for air conditioning, and reduced storm-water pollution. This is in line with Steve Mouzon's theory of "walk appeal" (Mouzon, 2010), that asserts that how far one walks is determined by what they encounter along the way. The walker would need sufficient "entertainment" from friendly and unique building faces, street-level windows (stores allowing for window-shopping), and architectural details in buildings.

3.3. Disruptive technology

Disruptive technology is a term referring to innovation or technology that shakes-up and drastically alters an established industry and could end up establishing a new industry altogether. The term was first used by Harvard Business School's Prof. Clayton M. Christensen in his book, "The Innovator's Dilemma" (Christensen, 1997). Contrary to "Sustaining Technology" which opines gradual improvement to an established technology, disruptive technologies often have numerous glitches in terms of their performance and refinement. This can be explained by the fact that they are new in the market, appeal to a limited and restrictive portion of the market and may not yet have a demonstrated functional application. An innovation could be revolutionary, but that does not make it disruptive. For example, a small organisation with limited assets, effectively challenging a more prominent more established organisation or reinventing the market, will have caused disruption and hence qualifies to be a disruptive technology.

Disruptive technologies in the recent past included the personal computer (PC) which displaced the typewriter and how people work and communicate, automobiles that displaced rail, cellphones and particularly the smartphone, which displaced landlines, ultrasound, which displaced radiography and X-rays, cloud computing, social networking, email, and so forth (Rouse, 2016).

The disruptive technology does not need to be superior to those existing in the market or offer better performance but could be more user-friendly, cheaper, and more convenient. They rarely make an immediate impact on the market instead take time until adopted by a 'critical mass' of users (Investopedia, 2018). Digital disruption has shaken up businesses over the last decade such that they are all trying to get ahead of the curve on a mission to predict the future, foster creativity and innovation, and create the next great niche idea before the next disruption occurs and finds them unprepared.

According to Prof. Christensen (Christensen, 1997), there are two types of disruption; 1) New market disruption, and 2) low -end disruption which is discussed next.

3.3.1. New Market disruption

This disruption happens when a product fits a new or emerging market and targets clients who were unserved by current offerings in the market. This type of disruption is subtle and often goes unnoticed by current market players because they emerge in new spheres of competition, which compete on varying scales of performance than the original/traditional spheres. This type of disruption differs to the low-end type, by occurring in a new sphere of competition (a new market), whereas low-end disruption, which is explained below, occurs at the bottom of the original sphere of competition. The market incumbents compete against "non-consumption" because their clients were inactive in the original market, perhaps because they lacked the money or skills to purchase and utilise the product. The incumbents have an edge when competition depends on producing better products costing more to existing customers than when producing a cheaper, more convenient product to either a previously unserved or new market, whereby disruptors and new entrants have the advantage (Christensen, 1997).

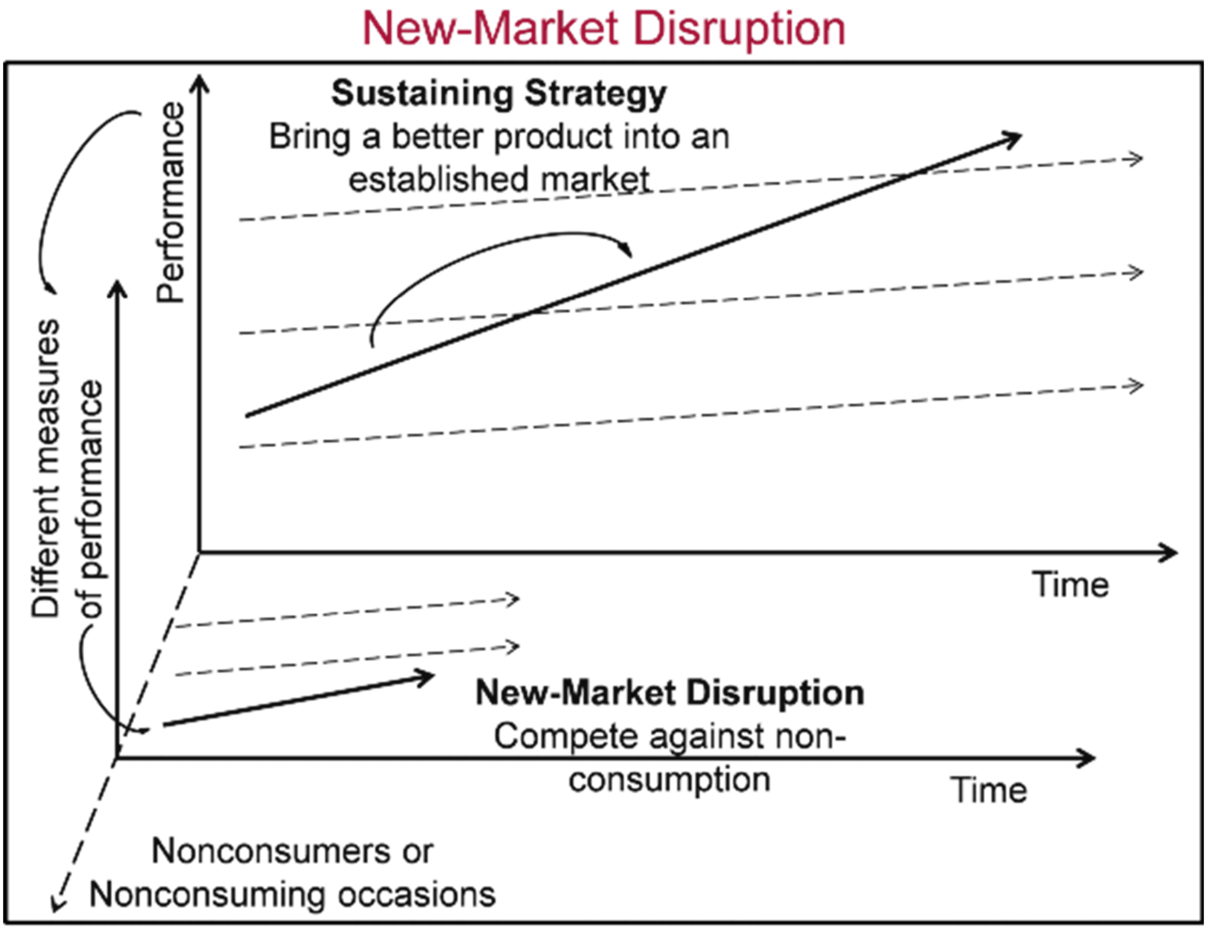


Fig. 3.8: New Market Disruption

(Christensen, 1997)

3.3.2. Low-end disruption

This disruption targets clients that do not require the complete range of capability of the innovation, contrary to those in the high-end segments of the market. It arises when the rate of improvement of the product is higher than the rate of customers embracing this new performance, hence at some level, the performance of the product overshoots the requirements of particular client segments. Technologies tend to progress faster than market demand (Christensen, 1997).

The focus is placed on serving the least profitable customer who is unwilling to pay higher prices for more performance and functionally-capable product (an upgrade) and is already content with a 'good enough' product. Once the disruptor has picked up a decent footing in this client section, his focus will shift to enhancing overall revenue and profitability, by slowly venturing into the market segments where the clients are willing to pay somewhat more for a quality upgrade (Christensen, 1997). Profitability will be achieved by the disruptor innovating further, and because the established dominant players in the market will do little to retain their market share in a low-profit market segment and will instead opt to move up-market and focus on their more alluring clients. If this process continues, the current established market dominators will be pushed to controlling smaller and smaller market shares and eventually, the disruptive innovation takes care of the demands of the most profitable market sector, outcompeting and driving the established organisation out of the market, i.e., the least-demanding customers abandon the incumbents for the new entrant (Christensen, 1997).

This type of disruption is facilitated primarily by the tendency of incumbent firms adding functionality to their products, thereby charging more money for them while investing less in R&D (Research and Development) and producing products that are costlier than the customers', particularly those in the lowest tier of the market, are willing to pay. That is the gap exploited by disruptors who do away with unnecessary functionality, thereby reducing the cost of the product (Klein, 2008).

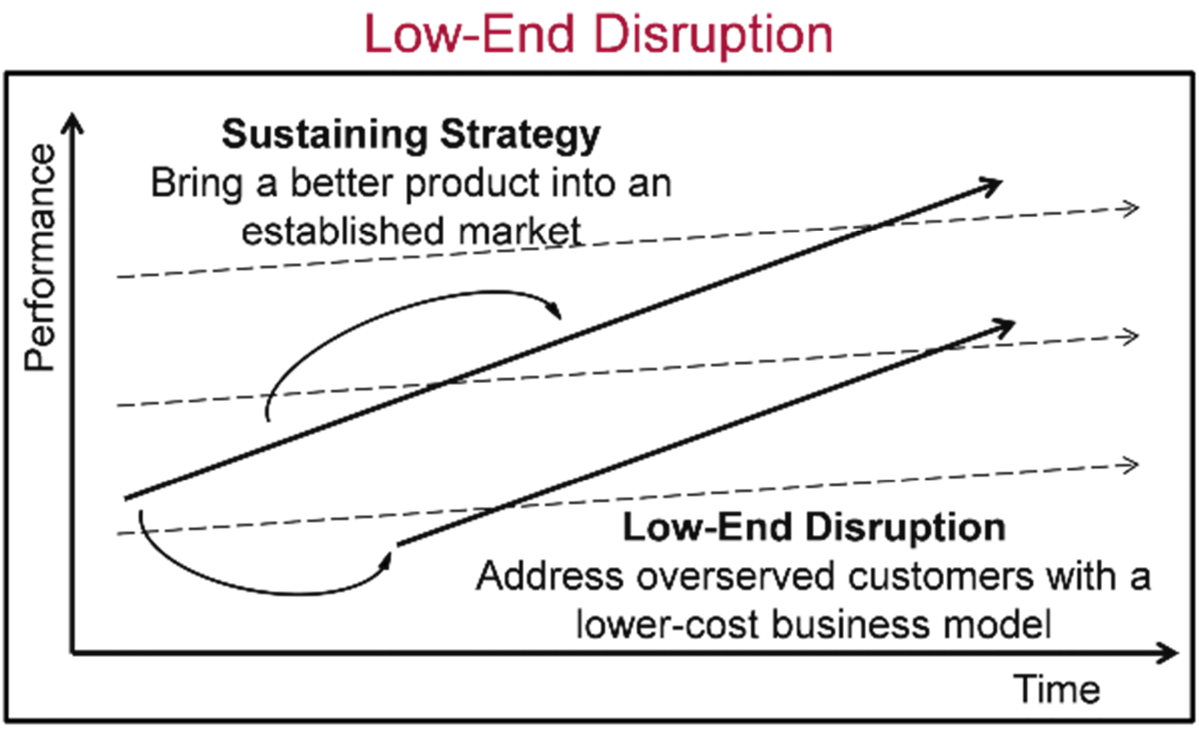


Fig. 3.9: Low-End Disruption

(Christensen, 1997)

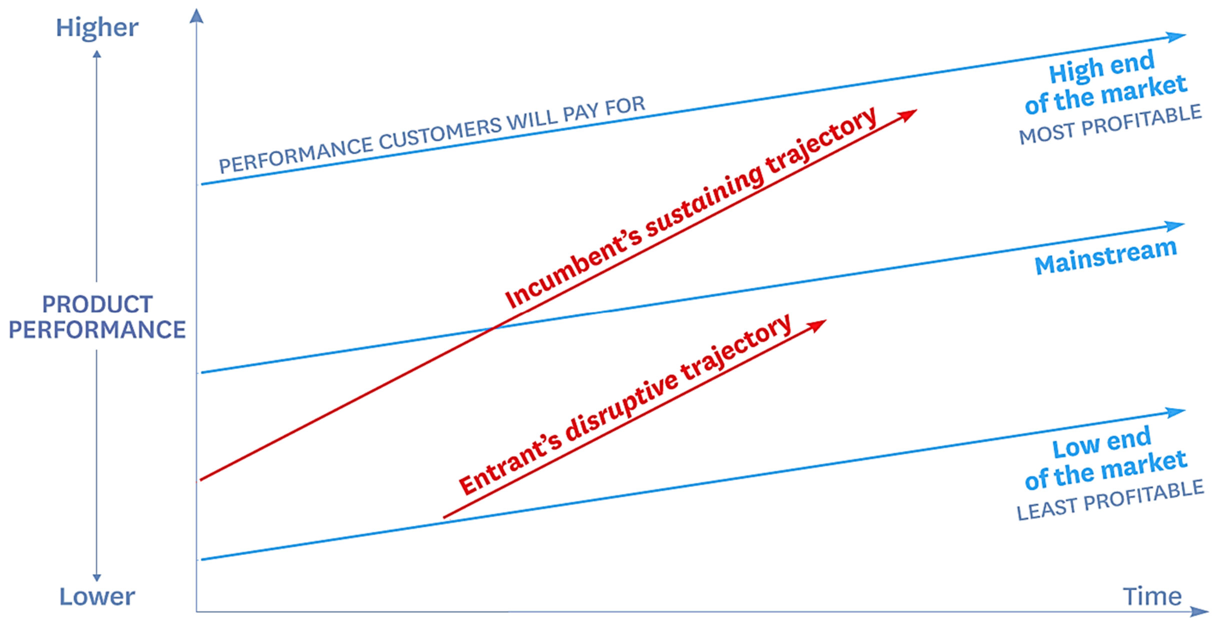


Fig. 3.10: The Disruptive Innovation Model

(Christensen, 2015)

The diagram illustrates customer demand trajectories (in blue), which show the willingness of customers to pay for improved performance, against product performance trajectories (in red) which show how products or services improve over time. To serve the high-end market segment where profitability is highest, incumbents introduce higher quality products or services (upper red line), often overshooting the needs of the mainstream and low-end customers. Because of this, a gap is created, allowing new entrants to serve the less profitable market segments neglected by the incumbents. The new entrants on a disruptive trajectory (lower red line) move upmarket to the high profitability segments and compete with the incumbents by improving the performance of their products and services (Christensen, 2015).

3.3.3. Sustaining Innovation

It is defined as an innovation that does not affect existing markets substantially and could either be evolutionary (improves a product in an existing market in conventional ways) or revolutionary (an unexpected innovation that does not alter existing markets significantly). This is targeted at the high-end market segments whereby customers are willing and able to pay higher costs for better products. This market segment is most profitable for incumbent firms by enhancing existing business practices and cost centres to take advantage of current competitive advantages (Christensen, 1997). Sustaining innovations are imperative for incumbents to compete against the current competition.

3.4. Big Data and Data Analytics

3.4.1. What is Big Data and Data Analytics?

The large quantities of crowdsourced information collected in the citizen science application of this *Walkability* application constitute Big Data, particularly when there is a large pool of users providing the information. This vast quantity of users' survey data provided would need to be analysed and interpreted to detect trends and draw meaningful conclusions.

"Big Data as a term has been in use since the 1990s, to describe the enormous volume of data –structured, semi-structured, and unstructured – that is so voluminous and complex that traditional data-processing application software is unable to handle and can be analysed for insights leading to better decisions and strategic business moves" (Sabrina et al., 2018). It necessitates the use of systems and technologies uniquely integrated to produce useful information from diverse, complex, and enormous datasets. Datasets are examined to discover new correlations because data in its crude form are of no value until analysed and decision-makers and organisational processes can then use the results.

Data analytics is not a new concept as many of its techniques; simulation, regression analysis, and Machine Learning have been in use for quite some time. It involves automating insights into a dataset and assumes the utilisation of queries and data aggregation techniques by effecting an algorithmic or mechanical procedure to conduct, analyse data, and obtain useful information (Monnappa, 2018). It is used in the travel, healthcare, gaming and energy management industries. In recent years, technological and software advances, new data sources (for instance, social media), and diverse corporate applications have led to the emergence of "data science" which incorporates the methods, tools, technologies, and procedures for analysing Big Data. Analytics is, therefore, the broad term for data analysis applications (Monnappa, 2018).

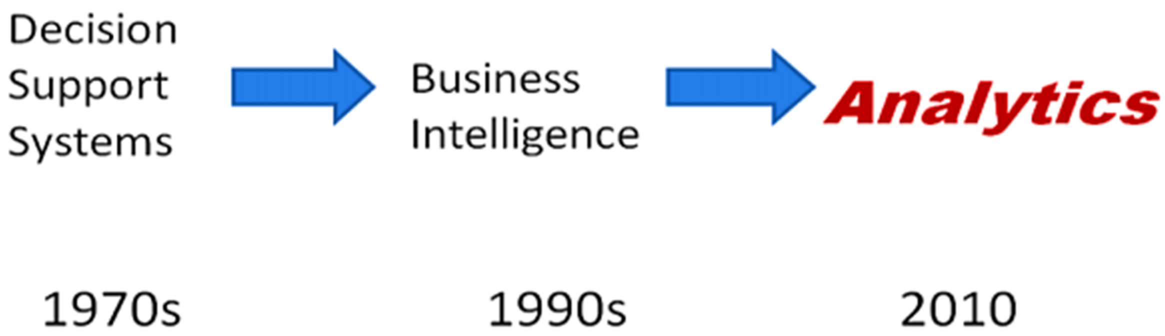


Fig. 3.11: Evolution of Analytics

"Machine Learning is the study and practice of designing systems that can learn, adjust, and improve based on the data fed to them. This typically involves the implementation of predictive and statistical algorithms that can continually zero in on "correct" behaviour and insights as more data flows through the system (Elingwood, 2016)."

The output from analysing Big Data should always be read in some context; otherwise, it could be open to misinterpretation. For example, data from social media sites should only be read as representative of a small proportion of the site's users and does not necessarily represent the views of the majority of users or the owners of the site. A typical example of Big Data in use is Google Maps, whereby having your location enabled on your phone, information about your location and speed is continually sent back to Google. That information on its own is not useful, but when combined with the information from the thousands of other people providing similar information, it gives Google a lot of data about where people are, how fast they are going, and what places they frequent on different days and times. With all that information over a long period, Google is able to predict with reasonable certainty what the traffic conditions could look like on various days and times of the week, and the best routes to use in your commute.

The company Netflix uses Big Data to give movie recommendations by having their algorithm learn from the data on user's clicks, watch time, most-watched movies, past viewing habits, and trends such as people who watch movie X typically also enjoy movie Y. This data allows Netflix to improve the viewing experience for its users. Coca-Cola in its 'Share a Coke' campaign used Big Data to select the most famous names among likely soda drinkers to print on their bottles. They did this by analysing data including gender and ethnicity, on a particular demographic, for example, 19 to 29-year-olds to decide on the names that would appeal to most people. This business decision, made by analysing Big Data to predict consumer behaviour, ended up increasing their market share in over 100 countries.

Data inhabits a range of file types, including; unstructured data, such as document files; streaming data from sensors, or structured data such as SQL database stores. It is defined and categorised by the 3Vs;

- Volume—Quantity of data
- Velocity—Rate at which data is created and processed
- Variety—Different types of data (text, images or sensor data) (Kumar, 2016)

Fig. 3.12: The 3 V's of Big Data (Rouse, 2016)

In recent times, the phrase "Big Data" has been used to describe the use of predictive analytics, user behaviour analytics, or certain other advanced data analytics methods that extract value from data, and seldom to a particular size of data set (Monnappa, 2018). The data analysis techniques commonly used include; Machine Learning, A/B testing, and natural language processing. It has elevated the demand for information management specialists, and in 2010, this industry was worth more than $100 billion and growing at a rate of 10% per annum: double the growth rate of the software industry in totality (O'Brien, 2017). The growth of data science has led to a cultural shift toward data-driven decision making and these cognitive systems will be a major disruption and will significantly impact the business landscape.

The rule of "5Vs" dimensions is now being used for Big Data, incorporating two new "V's";

- Veracity: Concerns the noise problem, the different anomalies in a large amount of data and the degree of significance of the stored data compared to the analysed problem.
- Value: Describes the quality of the enormous amount of data and the explicit or implicit relationships between data (Sabrina et al., 2018).

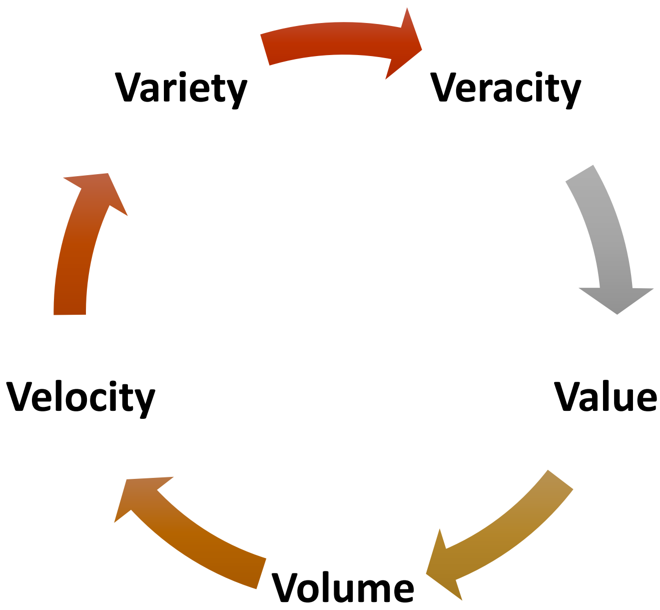


Fig. 3.13: Big Data 5V's dimensions

3.4.2. Sources of Big Data

There are countless sources of Big Data. A typical example would be the capturing of mouse clicks on an online shopping site, in Web log files, which can then be processed to understand online shopping behaviours and possibly influence shopping by dynamically recommending products. Social media generates large amounts of data that can be captured and analysed to understand it better; for example, what people think about a new line of products.

Big Data can further be broken down into Structured, Semi-Structured, and Unstructured Data. Unstructured data is information that does not reside in a traditional row-column database, is not easily searchable, and often includes text and multimedia content such as e-mail messages, videos, photos, social media posts, satellite imagery, and audio files.

Structured Data, on the other hand, is the data stored in fields in a database and generally resides in a relational database and can be easily mapped into pre-designed fields and is easily searchable (Datamation, 2018). A third type emerges from the two, Semi-structured data, which is information that does not reside in a relational database but has some organisational properties that make it easier to analyse. Examples include XML documents and NoSQL databases. It is estimated that about 80% of business data is unstructured and continually growing as businesses become increasingly digital; hence there is a great need for technology to determine what data is useful and relevant for further analysis to make quicker and more informed decisions. Organisations use only 5% of their available data. A 2010 study by Steve LaValle, showed that top corporates used Big Data at least five times more than underperforming companies, and that was no coincidence (Crossland, 2012).

	Structured Data	Unstructured Data
Characteristics	• Pre-defined data models • Usually text only • Easy to search	• No pre-defined data model • May be text, images, sound, video or other formats • Difficult to search
Resides in	• Relational databases • Data warehouses	• Applications • NoSQL databases • Data warehouses • Data lakes
Generated by	Humans or machines	Humans or machines
Typical applications	• Airline reservation systems • Inventory control • CRM systems • ERP systems	• Word processing • Presentation software • Email clients • Tools for viewing or editing media
Examples	• Dates • Phone numbers • Social security numbers • Credit card numbers • Customer names • Addresses • Product names and numbers • Transaction information	• Text files • Reports • Email messages • Audio files • Video files • Images • Surveillance imagery

Fig. 3.14: Differences between Structured and Unstructured Big Data

(Source: Datamation, 2018)

Currently, digital data is doubling every two years, and according to IBM, 2.5 billion gigabytes (GB) of data were generated every day in 2012, and by 2020, about 1.7 megabytes (MB) of new information will be created every second for every human being on earth (Monnappa, 2018). 2.5 extrabytes of data are created daily, and 90% of the data in the world has only been generated between 2015 and 2017. Legacy systems and incompatible standards and formats limit the integration of data and its analysis. McKinsey Global Institute approximates that retailers using Big Data effectively could increase their operating margins by up to 60% (Donovan, 2018). This includes **metadata** which is also created and is a set of data describing or giving information about other data (data about data).

Globally, there are four and a half billion mobile phones, and almost two billion people are going online. In the period, 1990-2005, over a billion people entered the middle class globally (United Nations, 2016), implying that an additional proportion of people became more literate, leading to information growth. To further illustrate the potential of yet unused data, 33% of stored information are in the form of alphanumeric text and still image data (video and audio), which is the format most useful for most Big Data applications (Sandri, 2017).

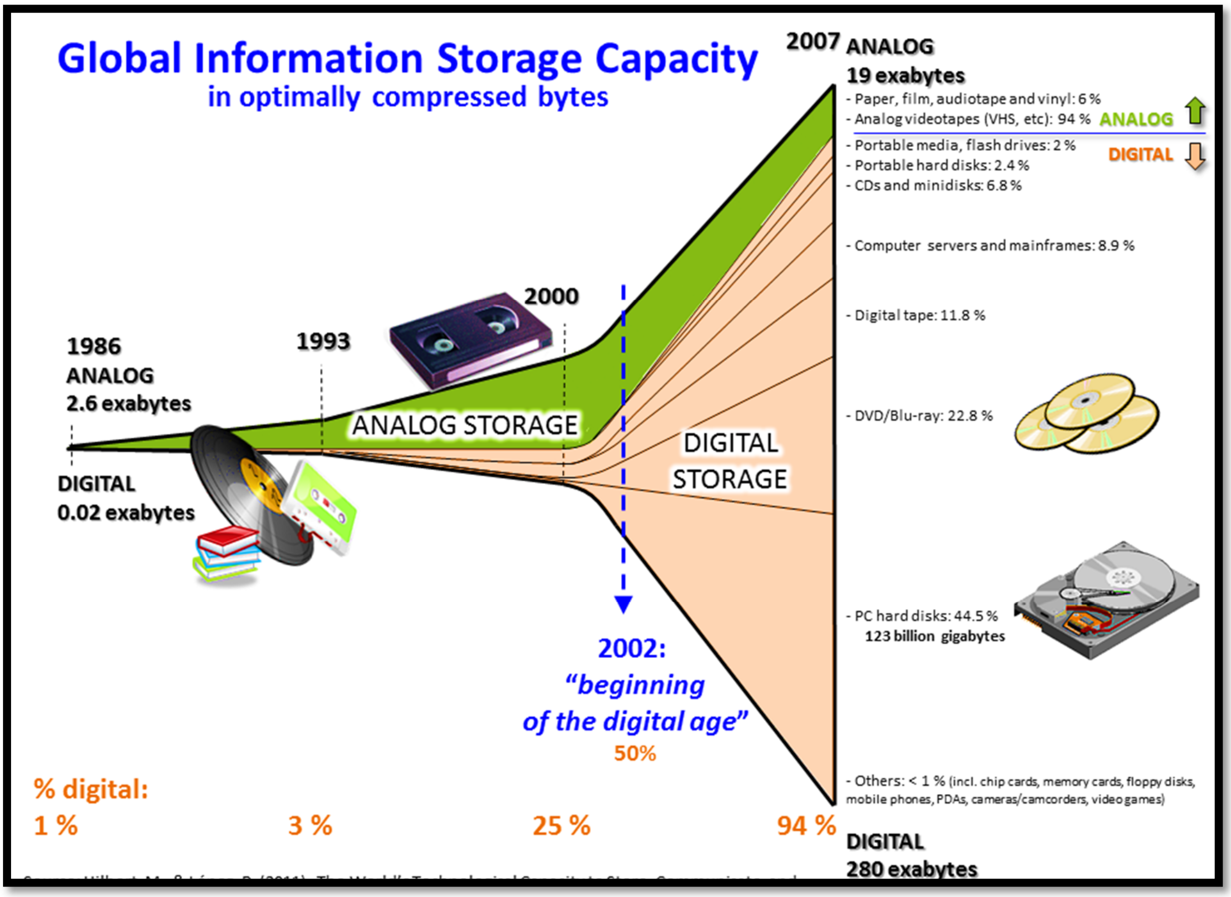


Fig. 3.15: Growth and digitisation of data storage

(Hilbert, M & Lopez, P, 2011)

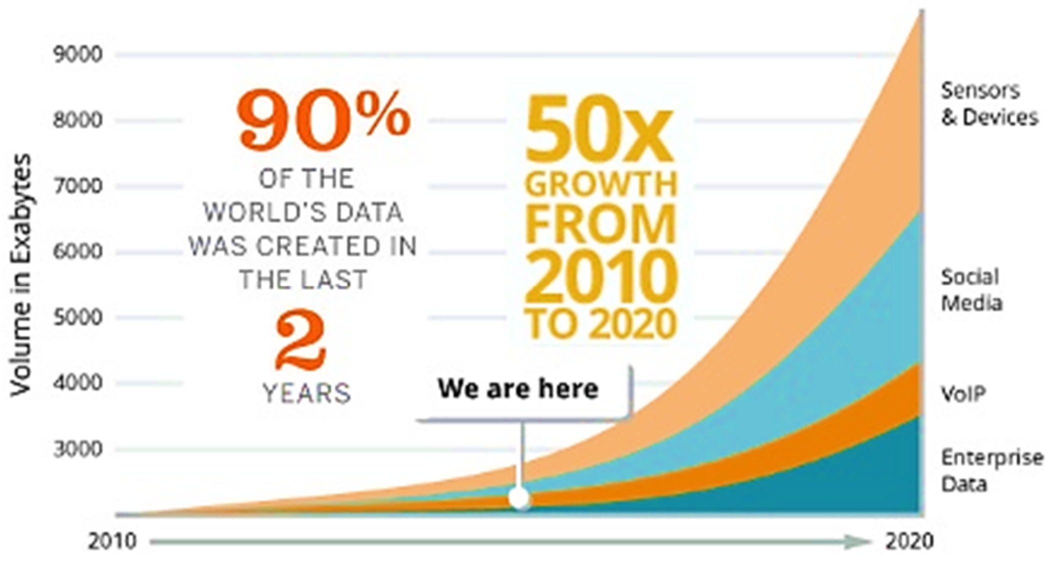


Fig. 3.16: Exponential growth of Big Data

(Panda, 2017)

Achieving high velocity cost-effectively is difficult; hence, many business leaders are unforthcoming in putting their resources into an extensive server and storage infrastructure that might only be used intermittently, to complete Big Data tasks. Consequently, public cloud computing has developed as an essential vehicle for hosting Big Data analytics projects. A public cloud provider can store large amounts of data and scale up multiple servers (hundreds) just long enough to accomplish the Big Data project, and hence the business only pays for the storage and compute time actually used, and the cloud instances can be turned off until they're needed again (Sandri, 2017). Organisations are gaining unprecedented insights into customers and operations because of the ability to analyse new data sources and large volumes of highly detailed data. This concept of examining large pre-existing databases to discover patterns and generate new information is referred to as **Data Mining/Data Discovery**.

Big Data continues to grow and become more essential because;

- The data currently gathered is unstructured and requires different storage and processing techniques compared to traditional relational databases;
- Available computational capabilities are soaring, implying that there are more exceptional options to analyse Big Data;
- The Internet has democratised data, gradually growing the data available whereas also amassing additional raw data.

(Struyk, 2013)

A recent study of 179 large publicly traded companies found that corporations that adopted data-driven decision making had yield and productivity 5-6 % higher than firms that did not, as well as greater asset utilisation, return on equity, and market value (Brynjolfsson et al., 2011).

3.4.3. Crowdsourcing and Citizen Science in the transportation paradigm

Crowdsourcing refers to a model of sourcing whereby an individual or organisation gets goods and services, both tangible and intangible (ideas), from a substantial, reasonably open, and varied/fast-evolving group of online users, in place of obtaining the function/input themselves. The result is thus an aggregate result, and because of the random nature of the crowd, the results could be from novices or experts, with no means of distinguishing the two. Editors Jeff Howe and Mark Robinson (Howe, 2006) of '*Wired*' first used the term in 2005, to depict how organisations were utilising the Web to "outsource work to the crowd". The main distinction with outsourcing is that crowdsourcing originates from a less-particular, more open (unnamed) group. Crowdsourcing's main selling point is the enhanced cost saving, speed, quality, adaptability, versatility, diversity, and a mix of top-down and bottom-up processes.

The crowd participants could be allowed to rank each other's contributions; although, this has the drawback that the earliest contributions have had more time to accrue 'likes' (Howe, 2006). This challenge is easily solved by utilising Ranking Algorithms that produce quicker results and make use of pairwise comparisons without penalising later contributions. Firms are drawn by the ability to obtain better results faster and cost-effectively, offload peak demand, and the large pool of participants available, thereby conduct research that would otherwise have been too complex to perform otherwise. The participants, on the contrary, are motivated by a combination of intrinsic (enjoyment-based and intangible) or extrinsic (immediate payoffs, delayed payoffs, and social inspiration) motivations (Clifford, 2017).

A popular application of crowdsourcing is crowdfunding which is simply an online method of raising money for a good cause (usually medical appeals) or a business idea by asking a large pool of online users to donate small amounts. The person seeking funding launches a campaign by providing information about his/her objectives, targets (i.e. in what time frame and the monetary amount being sought), and a persuasive pitch on a crowdsourcing platform such as Kickstarter, GoFundMe and Indiegogo. Crowdfunding falls into three types; donations, rewards, and equity-based (buying shares in a company) (Clifford, 2017).

In the transportation sphere, Big Data analytics can help identify the root causes of congestion by determining the true origins and final destinations of empirically measured real-world trips (Clifford, 2017). Transport practitioners can then discover whether for instance, insufficient parking is the cause of congestion, or if it is due to other factors like poorly timed traffic lights or an increase in commercial truck deliveries. If parking is the problem, the analytics can pinpoint where exactly drivers are searching for parking and where to focus their attention. Data collected by mapping and commute applications can indicate how long the average commutes in an area are, their start and endpoints, and the profile (characteristics such as age, and trip purpose) of those taking the journey. Transport planners can then assess if those commuters have reasonable access to mass transit options other than driving. If the commuters still drive despite access to public transport, planners can then explore incentives to encourage churning to mass transit and measures like carpooling.

Big Data using mobile phone devices can aid in identifying the top origin-destination pairs during peak AM and PM commuting hours revealing where the most substantial first-mile/last-mile transit gaps are located making it easier to identify the potential transit routes that will encourage churning to transit and also aid in the locating of future transit stop locations. The data could reveal transit gaps and expansion opportunities and allow for more accurate predictions for capacity expansion, so planners target new transit investments in the most useful places. This could also include the planning and implementation of electric vehicle (EV) charging networks in ways that encourage more widespread adoption (Clifford, 2017).

Also, using real-world travel behaviour data that is less opaque and more easily understood can strengthen planners' motivations for more government and private sector investments in transit. In terms of improving the accuracy of data, Big Data can aid in the accurate measurement of the Vehicle Miles Travelled (VMT) and separately categorise the VMT contributions of personal trips and commercial trips. Because estimates obtained from smartphones are based on real-world travel behaviour, they are typically more accurate for smaller urban areas than broad regional estimates. Using inaccurate or outdated data slows down the planning process and increases the likelihood that infrastructure projects will not meet the needs of today's and future users (Clifford, 2017).

Citizen science is a closely related concept whereby the public participates in scientific research often in collaboration with or under the direction of professional scientists and scientific institutions. It is, therefore, the forms of scientific research that involve people without scientific training at various stages of the scientific process, i.e. data gathering, data processing, or data analysis stages. It may be performed by individuals, teams, or networks of volunteers. In the data-gathering stage for example, the public can provide the data using their mobile phones (preferably using the sensors in the phone), which can be as easy as taking a photograph which has geolocation data attached to it, which can then be shared to a website where that data would form part of an aggregate picture.

Another popular form of citizen science in the data-gathering stage is where users are shown a photograph on a website and asked to state what is shown on the photograph and that information is then used to train the algorithm in machines (Artificial Intelligence) to identify that and similar objects or features in photographs. It has shown that people want to contribute to science, and citizen science data including the scientific outcomes from it is often openly accessible (publicly accessible open data) to anyone. Lately, the field of citizen science has expanded even more rapidly with the development of smartphones, allowing more information to be shared through digital media. Smartphones with built-in GPS receivers have allowed people to provide large volumes of geo-location information in real time readily.

In Kenya for instance, Big Tech companies from Silicon Valley and all over the world are paying some of Kibera's (Africa's largest slum) one million residents, to collect 'training data' used to programme self-driving cars. The about 1000 (paid) volunteers take pictures and then trace around objects in the images such as people, vehicles, road signs, road markings, specifying whether it is overcast or sunny in the pictures, et cetera. This information is then fed into the artificial systems to train them to recognise these objects and become "smarter". These companies take advantage of high digital literacy among the youth, and the low wages in developing nations like Kenya (Lee, 2018).

It is evident from the discussion above that the future demand from the transportation sector is for crowdsourcing and the collection and analysis of Big Data. In attempting to solve the myriad of transport problems, there is a need first to have good reliable data. The high costs associated with obtaining excellent and reliable data, in terms of financial cost and time costs, and then analysing this data, is often too steep using conventional tools. However, collecting and analysing Big Data using smartphones can drastically reduce this cost and provide much-needed transport information quickly and comprehensively. The ongoing wave of innovation opens a range of exciting new possibilities, but care should be taken not to only focus on car-centric development.

3.4.4. Limitations of Crowdsourcing and Citizen Science

The impediments of crowdsourcing are primarily that the quality of results is uncertain because, in the absence of vetting, anyone can contribute to the results. Often, the quality of the results is determined by the number of contributors, which is affected by the rewards offered (financial or otherwise). Sorting out the results to separate the high-quality and thus useful results from unusable results creates overhead costs. The task design such as fixed classes (choices) would pointlessly limit quality when contrasted with when contributors give free-form information, compared with tasks whereby they selected from a set of limited options.

Crowdsourcing also disentangles the capital-raising process, allowing entrepreneurs to focus their time and energies on the project rather than financing, thereby improving efficiency and innovation. The underlying data-mining methods are only able to purge erroneous user reports from a database when there is enough volume of data provided by the crowd (Clifford, 2017). User “buy-in” into a platform is critical for this self-cleaning mechanism to work even though, in the initial stages, there is no guarantee that a critical mass of users will be achieved. There is, therefore, more incentive to minimise any factors that could hinder uptake, such as requiring high technological know-how which can present a steep learning curve for users.

Critics opine that the simplified access to capital, in the form of a large pool of smaller investors, could end up negatively affecting the project (Lee, 2018). This is because the small stakes by each investor, allow them to be less risk-averse. The entrepreneurs also lose out on the experience persuading risk-averse investors since they do not rely on one single investor for the survival of their venture, and they are able to find replacement investors to invest quickly. Proponents, however, contend that crowdsourcing is advantageous because it permits niche ideas that would not survive venture capitalist or angel funding, which increases the number of projects and by correlation, on the flip side, increasing the number of failed ideas and concepts. From a legal perspective, fair labour practices are frequently flouted because crowd workers are deemed independent contractors and not employees, therefore not guaranteed the minimum wage or fair remuneration (Lee, 2018).

Citizen science is particularly limited in that were the volunteers to lack proper training in research and monitoring protocols; they are at risk of introducing bias into the data.

Participation is unequal and favours those with certain socioeconomic advantages such as access to a reliable and cheap data connection, income levels, educated populations over uneducated people, availability of spare time, and the location. Volunteers may also lie about data, and this risk is even higher when rewards are given as an incentive to participate.

3.4.5. Privacy concerns of Big Data

For the most part, as Big Data and the statistics we do with it permeates more areas of our lives, new problems emerge. The quantity (volume) of data is so vast that we have to rely on algorithms to manage it, but how much can we trust those algorithms and those who use them? Also, depending on the enormous volumes of raw data fed into the algorithms to train them, we can inadvertently introduce bias which is detrimental particularly for algorithms used to determine mortgage rates, insurance rates, or assess the risk someone might do something illegal in future. The output from these algorithms depends heavily on input data they were trained on, i.e. Garbage in, Garbage out (GIGO). That raw data needs to be as representative as possible.

Because of the predicted exponential increase in accumulation, storage, and mining of Big Data, there is a legitimate concern of individual privacy in terms of what data governments or organisations should be permitted to gather, and the protections that should be implemented for its ethical use and dissemination/sharing. Generally speaking, large databases have a high likelihood of containing highly sensitive and private information, but the large size of data can make implementing security and privacy controls such as encryption, cumbersome and expensive. The companies collecting our data need to be more transparent with that data such as how their algorithms are using that data because they have a responsibility to protect our data.

Given these points, people need to understand who has access to their private information, what they are doing with it, who are they sharing it with, and what assumptions are they making about you with the data they have. Concerns are raised when large multinational corporations utilise data from varied sources, i.e., data blending, to accurately understand an individual, where they live, where they commute to, their acquaintances, companions, and what they spend money on. The purpose of doing this could be virtuous like with the intention to make more appealing personalised shopping offers, but it also could be utilised for less benign purposes such as determining whether to increase an individual's insurance rates based on the risky activities they undertake (Clemons et al., 2014).

All things considered, some argue that privacy is not a legitimate concern as it facilitates enhanced customer service and personalised marketing and offers, and other useful benefits. A recent scandal whereby a data analysis firm, Cambridge Analytica, illegally accessed personal information obtained from over 87 million Facebook profiles to create a psychological profile of the individual users and target them with personalised political advertisements to influence the outcome of the 2016 US election. The same was done in other countries, without the individual's consent, in an attempt to influence voters and sway elections (Greenfield, 2018). These massive quantities of private information are also vulnerable to theft, such as by hackers.

Better technology allows for more protection like encryption, but it also exposes our data to broader scale and more sophisticated breaches.

3.5. Data mining, processing and interpretation of the information collected

Having collected crowdsourced survey and geographic information using the smartphone sensors, the question now becomes, how we mine and draw reliable conclusions out of the information contained in the geographic databases. There are two methods. Cartographic visualisation using maps is one way, by visually representing geographic information in the form of maps. This method is however not error-proof. The information contained in these maps and the underlying spatial databases require accounting for possible errors when wanting to draw summations from them.

A more accurate method to interpret geographic information is using statistics. Statistical techniques assess and maintain the quality of the information. Different statistical techniques are used depending on whether the data is normally distributed or not. Were a random sample to be taken from a population, that sample would represent a miniature version of the population it was drawn. Descriptive statistics such as the mean, median, range, variance, histogram, et cetera, can then be used to deduce information about the population by hypothesis testing. For example, whether the medians of population A and population B differ.

Instead of trying to get a complete picture from one individual data enumerator, why not try a different data collection alternative that instead of seeking completeness, seeks quantity and a higher response level, so that statistics can be used to triangulate the true picture. This is probably a more robust approach than that of a single enumerator because we are also looking for temporal dynamic (time-based patterns and trends) in those observations, which would possibly have been lost when doing intense enumerated data collection methods. An enumeration is a complete, ordered listing of all the items in a collection or all the elements of a set. The enumeration can be as simple as natural ordering (such as 1, 2, 3, 4), or imposing an arbitrary ordering.

A temporal dynamic, referring to a periodic regularity, or, a once-off or irregular past, present or future of an element, is driven by predictable and unpredictable time-based events and phenomena (Whiting, 2015). This is because those tend to focus on one moment in time instead of covering multiple times. So long as it is engaging for the user to interact with the application, a whole trajectory of data can be obtained. This new approach would also reduce the cost of the data collection because the cost of data collection linearly goes up as one tries to cover a stretch of road, both in time and space. In other words, the completeness in the survey would linearly cost more money. The responses would then be combined and aggregated along these data dimensions to ensure, for example, that a feature, like a pothole or street light, has more than five observations over a defined period, say two weeks. Those five observations could then be combined to get more robust information on that particular pothole.

3.5.1. Parametric and non-parametric statistical techniques

Parametric methods in statistics assume a probability distribution based on some fixed parameters (a characteristic of a population, such as mean, variance, median, range, et cetera.). They are used to measure hypotheses that are small and makes more assumptions about a given population. When the assumptions are correct, they provide higher accuracy and more precise estimates, but when the assumptions are incorrect, the probability of failing is higher (Ogee, A, et al. 2015). A statistical test involving parametric statistics must, therefore, be appropriately qualified, for instance, "If the population is normal then..."

The advantages of these parametric tests include the following:

- Work well with skewed and non-normal distributions;
- Work well when the spread of each group is different;
- Have more statistical power than non-parametric tests, hence the increased likelihood of detecting a significant effect if it exists.

(Ogee, A et al. 2015)

In the non-parametric model, the parameter set (or feature set in Machine Learning) is fluid hence can change if more information is provided. The interpretation does not rely on the population fitting any parameterised distributions and does not assume a fixed model structure, i.e., ideal for unknown distribution models. They are often used for populations that take on a ranked order, such as movie reviews receiving one to four stars, and because they make fewer assumptions, their applicability is much broader and are more robust, and have more simplicity. On the flip side, a more significant sample size requirement is necessary to provide conclusions with the same level of certainty. Most nonparametric tests assume that the population is continuous and have the same shape, which works well for biological data. The advantages include:

- The study area is represented more accurately by the median (the mean is a poor indicator of the central tendency for the data);
- Ideal for small sample sizes;
- Not adversely affected by outliers and can handle ordinal and ranked data.

(Ogee, A et al. 2015)

The choice between parametric or non-parametric tests is mostly contingent on whether the mean or median more accurately represents the centre of the data's distribution. If the parametric model of the population does not match the true shape of the population, the assumptions of the parametric test are broken, and the parametric test cannot be used. When the distribution is skewed enough, the mean is strongly affected by changes far out in the distribution's tail, as much as the median continues to reflect the centre of the distribution more closely. If the mean accurately represents the centre of the distribution and the sample size is large enough, a parametric test is ideal (Ogee, A et al. 2015).

However, if the median represents the centre of the distribution, the non-parametric test is ideal, even for large quantities of data samples. Nonparametric statistics replace specific distribution functions with very general assumptions about the sample population like that the populations are symmetric (Ogee, A et al. 2015). They are more appropriate when the data contains errors (referred to as “dirty” data), and where obtaining quantitative measurements is impractical. They are also arithmetically simpler to do and understand.

3.5.2. Data Aggregation and Clustering

Data aggregation, the process of aggregating (combining) the data from multiple sources (such as sensors) to eliminate redundant data and only make use of the most critical and most useful data for analysis and processing, is generally applied on Big Data which does not provide much information value. This is done to present findings in a summarised format useable by the end-user or application. This is an efficient way of dealing with voluminous data by combining similar data, eliminating redundant data, and therefore reducing the resource consumption (referred to as energy-saving) (Sabrina et al., 2018).

Clustering, on the other hand, is a method for statistical data analysis, to group a multi-dimensional data set into closely related groups, such that there are similar traits within groups. Objects are grouped according to their fit to descriptive concepts, and not according to simple similarity measures. The clusters are made up of groups of statistically significant data, both high and low values, within a dataset. Because many users are providing geographical data, there is a need for a way to process that information to obtain trends and other useful information from it. Clustering is done to determine the intrinsic grouping in a set of unlabelled data and its usefulness increases as the size of data providers and the extent of the study area increases because visual analysis for trends in extensive spatial data becomes increasingly challenging.

With the advancements in GIS technology, spatial statistical analysis tools have greatly improved to have the ability to run complex graphical algorithms in the analysis of patterns. The various statistical analysis tools can thus be applied to the users’ ratings of the walkability defining parameters such as the state of footpaths, the presence of ramps and trees, level of noise, et cetera, to identify clusters of low/high ratings of walkability. By inference, a clustering algorithm should, therefore, have the following attributes:

- Scalability, interpretability and usability;
- Ability to deal with various types of attributes;
- Deal with noise and outliers;
- Insensitivity to order of input records;
- Handle high dimensionality.

(Rashid, 1999)

Clustering algorithms do not often meet all the above requirements because of complexity and the time consumption of dealing with many items and dimensions. The results can also often be interpreted in different ways because of their being arbitrary.

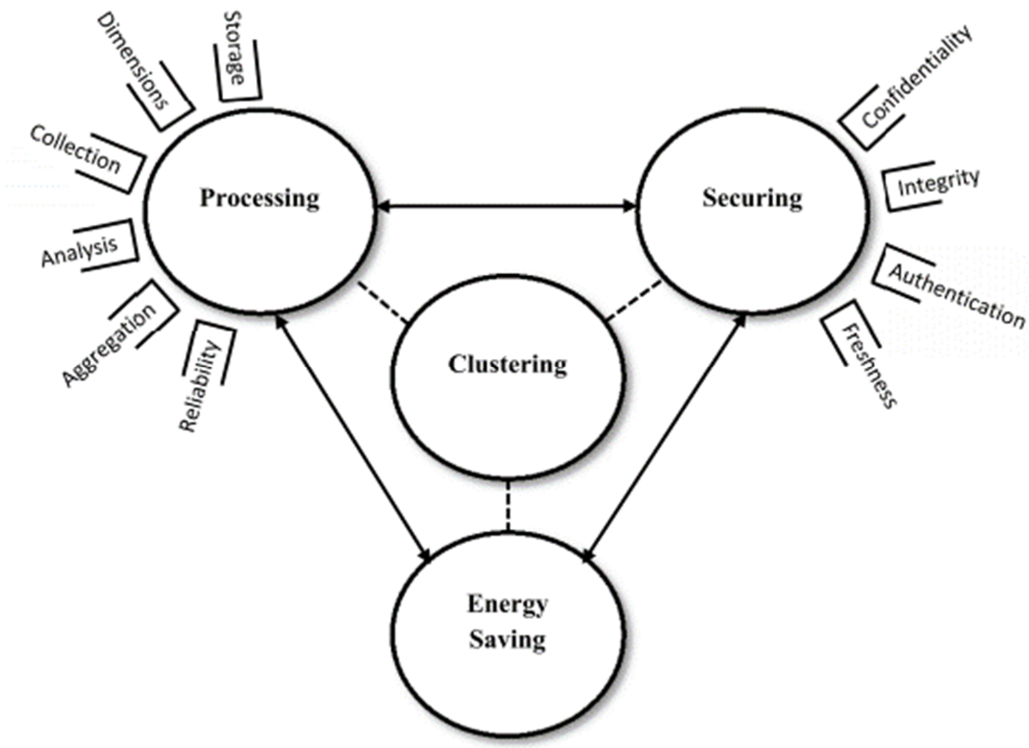


Fig. 3.17: Process of analysing Big Data

(Sabrina et al., 2018)

Geo-clustering when analysing the data, whereby different observations close to each other can be combined into one observation based on the assumption of their similarity, must be done only using actual observations and not those predicted by the application algorithm. The actual observations help the algorithm to improve itself.

3.5.3. Machine Learning

3.5.3.1. What is Machine Learning and its relevance to mobile phone applications?

The term 'Machine Learning' was first coined by Arthur Samuel in 1959 (Puget, 2016) as a technique of data analytics that teaches computers, using computational algorithms, to learn from experience rather than being explicitly programmed to reach a particular conclusion, i.e. without reliance on a predetermined model equation. For example, data about past traffic patterns at an intersection could be fed into a Machine Learning algorithm to predict future traffic patterns at the intersection. The data fed into the machines are in the form of observations and real-world interactions, then the algorithms figure out how to perform the tasks by generalising from examples. Conversely, because of the complex nature of most real-world scenarios, designing such an algorithm to produce accurate results for all cases, is impractical. Machine Learning is, therefore, an application of Artificial Intelligence and is particularly useful for solving problems that cannot be solved by numerical methods alone (MathWorks, 2018).

Machine Learning is, therefore all about algorithms that give computers the ability to learn from data and then make predictions and decisions. These algorithms discover natural patterns and trends in data to generate insights for better decision making and predictive analysis. It is particularly useful when the rules of a task are too complex, keep changing, or changing nature of data necessitating the program having to adapt constantly (Puget 2016). Just like other data analysis methods, Machine Learning poses a host of ethical questions. For example, systems trained on datasets collected with biases may perpetuate these biases by producing results that propose measures that will continue these biases.

Training the system takes considerable time and resources and integrating Machine Learning with Artificial Intelligence (AI) can make it much more efficient in processing Big Data. Machine Learning can be used in computational finance in credit scoring, natural language processing in voice recognition applications, email filtering such as identifying spam, data mining, personalised movie recommendations, image recognition, object and motion detection, computational biology in DNA sequencing, optical character recognition (OCR), and other expert systems. In the transport sense, provided with a large set of data points, a Machine Learning algorithm could, for example, notice a trend of different traffic behaviours between the different age groups or between the different genders.

3.5.3.2. Types of Machine Learning

There are two basic techniques for Machine Learning. Choosing the proper algorithm for your data is crucial and is mostly by trial and error to see which works best for the data, its size, and the type of results envisaged. The biggest reason for algorithms not performing as expected is because of problems with the training data, such as the data being insufficient, skewed, or insufficient features describing the data for making decisions. Consequently, it is essential to reserve a share of the training data set for cross-validation; so that the chosen classifier or learning algorithm performs well on new data (Faggella, 2017).

Also, the more high-quality data and examples provided, the more the system can learn and return more relevant outputs and work at its optimum levels. Higher-quality outputs are only possible if the training is done continuously and frequently, with increasing amounts of data because the system improves its knowledge only by adding more data repeatedly. However, too much data of the same genre makes the system less accurate for example; the system will only be able to distinguish different meanings of a word (or phrase) if the word is used in different contexts in the datasets available to it. Accordingly, the quality of the output is determined by the quality and quantity of the input (MathWorks, 2018).

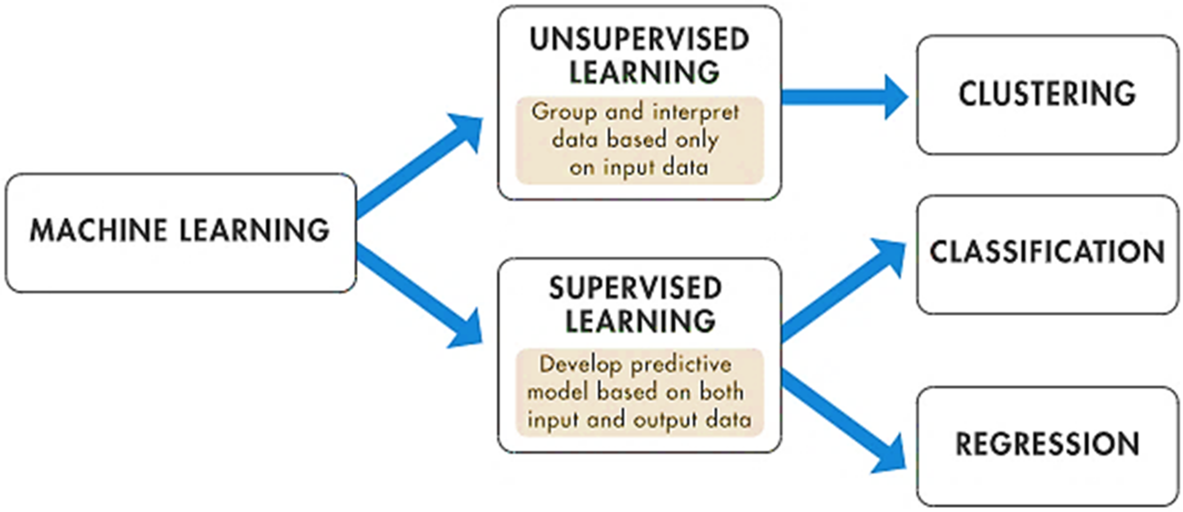


Fig. 3.18: Types of Machine Learning

(MathWorks, 2018)

a) Supervised Learning

The program is trained on a pre-defined set of examples- input and output data, to generate or predict an accurate output when fed new raw data. The model makes predictions based on evidence in the presence of uncertainty (MathWorks, 2018). This type of learning is used when the expected output data is known, i.e. takes data that already has a correct answer. The algorithm can then compare its output with the expected output to find errors and improve its model. It is supervised because we can tell the model what it got wrong, and it is Machine Learning because instead of following strict rules and instructions from humans, the computer learns how to do things from the data. For example, it would use images that have already been labelled as "cat" and "not a cat" to try and predict whether an unlabelled image is of a cat or not.

It makes use of classification and regression techniques to develop predictive models. Classification techniques predict discrete responses and the models classify the input data (MathWorks, 2018). These are systems where we seek a yes-or-no prediction, such as "Is the tumour malignant?" The data used therefore must be able to be categorised or separated into specific clusters. This technique is often used in speech recognition and medical imaging.

Regression techniques predict continuous rather than discrete responses (MathWorks, 2018). These are systems where the expected output lies within a spectrum, i.e. "How much?" or "How many?" or if the response is a real number, such as pressure readings. This technique is often used in predicting electricity loads. Other types of supervised Machine Learning models include logistic regression, linear discriminant analysis and K nearest neighbours.

b) Unsupervised Learning

The program is given a range of data and must find hidden patterns or intrinsic structures and relationships in the data. The most utilised technique is clustering, which is used for exploratory data analysis to find trends or clustering in data (MathWorks, 2018). A set of observations is assigned into subsets so that observations within one cluster are alike, according to a predetermined criterion. Each cluster has its assumptions about the data structure and separation between different clusters. Because the groups do not already exist, they are referred to as unsupervised, and unlike supervised Machine Learning, we cannot give the models feedback on whether they are right or wrong (MathWorks, 2018). There are no “true” categories to compare the groups. Typical applications for cluster analysis include object recognition and gene sequence analysis. A mobile service operator could optimise the location placement of cellphone masts by using Machine Learning to approximate the clusters of clients that would need to use particular cellphone masts. There are two main types of clustering; K-means and hierarchical clustering.

c) Semi-supervised and Reinforcement Learning

Semi-supervised falls between the two other types of Machine Learning because it makes use of both labelled and unlabelled data for training, allowing the system to improve its learning accuracy (MathWorks, 2018) continually. This type of Machine Learning is selected when the acquired labelled data require skilled and relevant resources to train and learn from.

Reinforcement learning is a method that allows for dynamic environmental interaction by producing actions and discovering rewards or punishment. Trial and error search and delayed reward are the most relevant characteristics, and it allows for automatic determination of the ideal behaviour within a specific context, to maximise its performance. Reward feedback (reinforcement signal) is used for the agent to learn which action is best (Varone et al., 2017).

3.6. Latest technological frontiers and developments

3.6.1. Augmented Reality

*“**Augmented Reality** (**AR**) is a direct or indirect live view of a physical, real-world environment whose elements are "augmented" by computer-generated perceptual information, ideally across multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory*.”(Arete IT, 2018).

Simply put, the natural environment is overlain with enhanced virtual information, which only the user can see and could be either an enhancement of the real-world environment or a facade of it. The first functional AR systems came online in the early 1990s, and the hardware necessary for AR is available in most modern smartphones including processors, cameras for optical projection, display, sensors (including accelerometer, compass, and GPS) and other input devices. AR devices are usually controlled using touch by sensing changes in pressure when the user taps or swipes, or voice commands picked up by the device’s microphone.

Mobile phone innovation has slowed down considerably in recent years with newer phone models only coming up with improved hardware components, but not much in terms of new innovations. Subsequent models of smartphones, for example, spot slightly faster processors, bigger and clearer displays, higher resolution cameras, and more accurate sensors, but nothing new or impressively revolutionary. The advent of Artificial Intelligence and Augmented Reality is likely to be that revolutionary innovation. Because of device sensors and the fact that people usually have their mobile phones with them at all times, this could allow the devices to learn, track, interpret, and respond to patterns and behaviours that it recognizes as relevant to you, and the more the data it collects, the more intelligence and useful information can be extracted. Currently, this processing of information and Machine Learning is not done by the device itself. Instead, it takes place in the cloud (back-end processing), because of the limited processor capacities on mobile phone devices. This cloud computing has the disadvantage that it can only be used reliably with a stable internet connection and data transmission would lead to unacceptable delays.

Most members of the public became aware of AR and got to use it because of the success of the viral cellphone game Pokémon Go launched in 2016 and had been downloaded over 500 million times before the end of that year. It is anticipated that the AR/VR, and mixed reality industry will have revenues of over $90 billion by the end of the current decade, even though only $700 million was invested in 2015 (Graells-Garrido et al., 2016). The game was credited with increasing the number of people out in the streets, improving access to public spaces, and improving general physical health, but its real impact on people's mobility patterns is still undetermined.

A study using data from mobile networks was conducted to evaluate the effect of Pokémon Go on the pulse of Santiago in Chile. The study results, after accounting for land use, daily patterns, and points of interest in the city showed up to 13.8% more people outdoors at certain times, even though they did not seem to be going their usual routes (Graells-Garrido et al., 2016). These effects at specific times were found by performing several regressions using count models over snapshots of the cellphone network. They found that on working days, during rush hour, there were more people in the streets implying that instead of people changing their daily routines, they somewhat tweaked them slightly to play the game. They found that on the weekends, people went out to play the game to places close to their homes (Graells-Garrido et al., 2016).

AR technology is applied in the medical sector to guide doctors through surgical operations, aviation sector to train pilots using simulations, corporate sector to train employees, manufacturing and construction sector to simulate developments and save material by placing virtual markers instead of real markers to designate where a beam should be placed for example, education sector to create interactive education contents, entertainment, gaming, and movie industry to enhance user experiences, shopping, travel, and marketing sector to provide visualisation, military applications allowing soldiers to have blueprints or overhead drone and satellite views overlain directly onto the soldiers' field of vision, among others.

There are four categories of AR;

i. **Image recognition/Marker Based AR**: A typical example of this is a QR/2D code used on shopping items whereby the device's camera and visual marker detect and read the QR codes/markers that have information overlain. QR codes are widely used since they are easily read and recognised using minuscule processing power.
ii. **Markerless/location-based/position-based/GPS AR:** Perhaps the most common AR application, the device's GPS, compass, and accelerometer are used to provide location-based information, which can be used for various location and mapping applications.

iii. **Projection Based AR**: This operates by projecting artificial light onto real-world objects and sensing the human interaction (i.e. touch) of that projected light. The detection is done by distinguishing between the expected base projection and the received projection after the human interaction. A 3D hologram can even be projected in mid-air using laser-plasma technology.

iv. **Superimposition Based AR**: The original view of something is completely or partially replaced with a newly augmented view by making use of object recognition to identify the object. This is the type of AR that would allow one to scan an object from a sales catalogue (physical or digital) and virtually have the object placed in their environment. An example is the visualisation of a table set in your living room.

(Reality Technologies, 2016)

AR has in recent times been applied and used in mobile phones, and more applications and use cases are still being produced. In the Netherlands, an application by the name *Layar* uses the device's GPS and camera to gather information about the nearby objects in the environment and then overlays information about those places on the phone's display. Similar apps such as *Holo* and *Lumyer* add moving Augmented Reality effects (holograms) such as celebrities, animals, and other characters, to videos and photos. A software called *Total Immersion* allows one to scan baseball cards using the device's camera, then shows related information and video about the player on the card and moving the card in view of the camera allows one to visualise on the screen the 3D figure performing actions such as throwing a baseball. The popular social media app *Snapchat* makes use of AR to provide unique filters and special effects, plus adding digital elements to real-life pictures. The app has over 166 million daily active users and is one of the most commonly downloaded apps on both Android and IOS platforms.

Geo-tagging applications have also started incorporating AR. The application *W.A.R (Widespread Augmented Reality),* lets people share information by tagging a location with a title and coordinates, and then sharing it onto the W.A.R. network, for others to find that location. Likewise, *My Augmented Reality* app helps one to keep track of where places are, so they can visit them later, and *ViewRanger*, *Augmented Reality Compass,* and *AR Compass 3D,* allow for real-time navigation by overlaying compass coordinates on top of the camera view, saving time checking bearings via a traditional compass and having to mark landmarks every so often. The ability to draw freestyle on camera images of the world around you open up a myriad of possible applications such as the *WallaMe* app that lets you share secret messages with others by turning the whole world into a blank canvas by pointing the device's camera at an empty surface such as a wall, and writing or drawing a message on the screen, then share it. Passers-by will have no idea that a message is there, but people with whom you have shared your creation with, and who stand in the same location, will be able to see the creation or drawing through their phones (Dube, 2018).

Google Translate combines AR with AI features allowing one to point their phone camera at a sign with text in another language and instantly see that text translated into one of 103 different languages online and 59 different languages offline. *Google Lens* in contrast, intelligently analyses a photo and provides all the information Google can find in it such as the various physical objects in the photo. An app called *Inkhunter* allows one to visualise how a tattoo would look on your body by wrapping the virtual tattoo around your skin in 3D. Almost similar to this, home design and décor apps such as *Ikea Place* and *Planner 5D,* which has over 16 million global users, lets you set up an accurate floorplan for your rooms and see how furniture, paint and other elements would look. InnoVision developers have created the *Meow ARCat* app that will allow users to raise a virtual cat through AR, such that they will be able to superimpose this cat onto the real world, so it will feel like one is raising and playing with a real-life cat. Popular games like *Ingress, Genesis AR*, *SpecTrek*, *Star Walk 2, Zombies Go!, Quiver*, *Silent Streets,* and *Pokémon Go* utilise AR to improve the gaming experience (Datamation, 2017).

It has recently been applied for industrial purposes as in the case of *vGIS*, the world's first holographic GIS, which uses AR to visualise underground municipal utilities. It is a comprehensive multi-device augmented-, mixed-, and virtual reality (AR/MR/VR) platform designed to power solutions that require advanced visualisations of GIS and other geotagged data. Presently, it has been deployed and piloted in over 30 cities and towns globally, in the municipal, utilities, energy delivery, and oil/gas exploration industries, where advanced visualisation technology can aid in improving productivity, safety, and facilitate better decision-making (Engineering Feed, 2018).

The National Aeronautics and Space Administration (NASA) has recently been working with Microsoft Corporation on the HoloLens platform, to train scientists and engineers through a virtual planet, say, Mars, by virtually immersing them on the Planet, and helping in figuring out exciting features to explore on that planet (Wenz, 2018). Future aeroplanes could phase out the use of windows and instead have AR views which would lead to sturdier and more aerodynamic aeroplanes which can be much faster and safer. Big Data and AI tools are increasingly being offered by organisations such as LinkedIn to sift through potential candidates' profiles and identify the most suitable people for a position. Such tools allow employers to find the best individual for any given job based on their skills, interests and actions.

There are some limitations of AR. As earlier mentioned, it relies on the device's sensors whose quality varies depending on the make of the device. GPS, for example, is only accurate to within 9 m and is unreliable indoors. Cellphone screens are quite small to be able to conveniently and fully display AR objects, and that is why wearable displays such as AR contact lenses, and smart glasses are gaining more traction. Internet addiction is already seen as an emerging societal problem, whereby people are starting to prefer virtual interactions to real-world interactions and could lead to increased social detachment and over-reliance on technology. Privacy concerns and how collected personal data is handled is an emerging issue because AR devices would require being constantly recording their environmental surroundings, for them to work as required. At the same time, facial recognition is deemed to be very intrusive. The data privacy concerns outlined for Big Data in this paper, apply here as well.

3.6.2. Artificial Intelligence (AI)

The term Artificial Intelligence was first coined in 1956 by American computer scientist John McCarthy (Moore, 2018). Artificial Intelligence, as an area of computer science, is best characterised as the ability for a machine or software to exhibit practices, including learning, behaviour, and communication with no discernible difference from that of a human being. The computers are programmed for the following traits; knowledge (the acquisition of information and rules for using the information), reasoning (using the rules to reach approximate or definite conclusions), problem-solving, perception, learning, self-correction, planning, and the ability to manipulate and move objects.

There are two types of AI; Weak/Narrow AI, which is an AI designed and trained for a particular narrow task, and the AI is only capable of simulating real human behaviour and consciousness. Strong AI is a system with generalised human cognitive abilities so that when presented with an unfamiliar task, it has enough intelligence to find a solution. The Turing Test, developed by mathematician Alan Turing in 1950, is a method or test used to determine a machine's ability to exhibit intelligent behaviour equivalent to, or indistinguishable from, that of a human being, under specific conditions.

It is predicted that by 2022, 80% of smartphones will have on-device AI capabilities, up from just 10% in 2017 (Moore, 2018). New AI processor chips being developed would allow devices to continue running Machine Learning algorithms, even when offline, reducing data traffic, and speeding up processing, while also saving power. AI in mobile phones will provide a myriad of benefits including;

Camera benefits- The phone’s camera interface will be able to use AI to detect the subject in the camera frame automatically (for example landscape, food, fireworks, et cetera) and immediately adjust the camera settings for the best possible image capture. AI could also identify facial features and automatically enhance them for a superior portrait.

Language translation and audio detection- There are already commercially available translation applications that allow the user to take a picture of something written in one language, then the application translates it to any other desired language and displays it on the phone’s screen. This, instead, is not done in real-time because the image is uploaded to the cloud or the internet for analysis and translation, then sent back to the device. Onboard AI on the device will be capable of translating the image in real-time, even without a data or network connection. The device could identify music playing or sounds around the device’s environment, using the device’s microphone.

User behaviour and device management- The AI system will learn and adapt to a user’s usage pattern, and after learning for some time, it would automate those daily processes for the user. They will understand who you are, what you want, when you want it, how you want it done, and execute those tasks for the user. Machine Learning would improve device performance and standby time. For example, using the various sensors, smartphones could better understand and learn user’s behaviour, such as when to use which application, and would, therefore, keep frequently used apps running in the background for quick re-launch, or to shut down unused applications to save memory and battery (Gartner, 2018).

Device Security- AI-based algorithms for device unlocking systems would identify a user's face for security and could even identify a face with changes such as spectacles or beard over time. Equally important, smartphones could learn a user's behaviour, such as walking style, swipe patterns, how they apply pressure on the phone, how they scroll and type, and use that as a security feature to grant access to the phone without the need for passwords or active authentications (Digital News Asia, 2018).

Voice assistants- Voice assistants could use AI through natural-language understanding to identify what a user says or their emotional states (through emotional intelligence and sensing such as by using the phone's front camera to understand a user's physical condition and gauge fatigue levels) and respond appropriately. They could also perform tasks such as placing an online order, creating a calendar entry, searching for lyrics to a song, and even drafting a message.

Better battery performance- Having the onboard AI processing on the device, will allow data to be processed and stored locally, eliminating the need for cloud computing which requires data to be sent to the cloud over the internet and takes significant processing power, which compromises battery life.

Content restriction- The device would be able to automatically detect restricted images, videos or text, and prevent the user from viewing them. This is useful when childproofing the device, preventing the viewing of photos of restricted or sensitive, high-security installations, or preventing the storing of highly classified data or private business information on the device. (Moore, 2018)

3.7. Mobile Phone Application Development Framework

3.7.1. Mobile Application Development

Traditionally, transport-related data has been collected in three ways; memory recall, game playing, and time-space diaries. For the collection of user perceptions of walkability, traditional audit-based surveying techniques typically focus on a paper-based or digital workflow that strongly emphasises the completeness of data collection along a journey, which as a result, often necessitates remunerated data collection agents. This makes such inventories tedious, inflexible, and unscalable. There is now a growing interest in keeping up with the times, and because of the declining survey response rates, by making use of Information and Communication Technology (ICT) in the collection of transport survey data, mainly using mobile phones, due to their prevalence also in developing countries.

Fig. 3.19: Modern smartphone

Early attempts at utilising mobile phones for this purpose focussed on using the network of land-based cellphone towers to triangulate the location of the mobile phone user. Later, there was the introduction of automatic transport mode detection, using positioning data as well as the phone's accelerometer data, and applying pattern recognition algorithms to the data to conduct a trip analysis. Respondents would no longer need to recall their travel patterns and itinerary because their phones would provide that information, which improves the accuracy of the analysis results, and saves time and monetary cost of conducting surveys.

It is crucial to define the design, structure, framework, features, and functions of a would-be mobile application before starting the code development. Application Programming Interfaces (APIs) facilitated the creation of apps that make use of web-based services, allowing users to access a range of information while on the move, but also share information about their activities (Gothankar, 2016). The cost of mobile app development is dependent on the features sought, complexity and platform to be designed. Implementation would depend on the type of application to be developed in terms of front-end (client-side) development, whether a native, hybrid, or web app, or back-end (server-side) development. Both front-end and back-end developers must consider a range of screen sizes, hardware specifications, and configurations when designing their application.

The application's User Interface (UI) should consider users' limited attention spans, minimise keystrokes, and be task-oriented with a minimum set of functions. This is part of user-centred design. The development team would ideally comprise a UI/UX designer, one developer per platform, backend developer, & a QA engineer. Depending on the scale of the project, a project manager, back-end developer, and an admin panel developer where the projects demand server infrastructure/API would be required. If all the expertise can be found in one development team, that would be convenient and possibly cost-effective.

Native apps are developed for a particular platform, whether Apple IOS, Android, Windows Phone, Symbian, or BlackBerry OS (Operating System) (Gothankar, 2016). The advantage here is that the user experience is optimised for the platform the app was developed for and have the highest security and responsiveness. The principal disadvantage is having to re-develop the app from scratch when intending to launch the app on a different platform, which is the reason for their high development costs.

Hybrid apps are installed on devices just like native apps but are mobile versions of web apps because they run via a web browser and are developed using HTML5 and JavaScript. They have the advantage of being cross-platform applications which save time and resources but are not as fast, reliable, or smooth as native apps. They also have access to various hardware/software capabilities through plug-ins.

Progressive web apps are not mobile applications but run in a browser and contain HTML5 based development that gives a native-like look and feel (Gothankar, 2016). They are easy to maintain, built using the most popular programming languages—so developer talent is readily available, and run on multiple mobile platforms.

The software development process can either be agile or not. An agile development process is based on iterative development, where requirements and solutions evolve through the collaboration between self-organising cross-functional teams (Gothankar, 2016). The decision on the development platform would depend on its traffic volumes and revenues, as well as its prospects in terms of how stable it is. As of 2016, Apple IOS had the highest traffic volumes at 65.17% and 45.77% average revenue return for applications on the platform. Android OS was second with 22.34% traffic and 45.44% revenue. Other OS platforms including, Windows Phone OS, Nokia Symbian, and Blackberry OS, accounted for the remainder.

In terms of the user base, Android controlled 80.2% of the global smartphone user base, followed by Apple IOS at 14.8%. There is also a cost to keep an application available on the various Application Stores, as well as cloud hosting costs for data generated by the application. R&D, marketing, and maintenance costs should also be factored for in the budget to allow for new features over time (Gothankar, 2016). The developers would also decide on whether to include a desktop tool, a web-based or cloud-based solution based on installability, portability to other platforms or hardware, performance and responsiveness, usability, and cost.

3.7.2. Industry Standards for Mobile Application Development

Any acceptable mobile application must meet the typical norms and standards in terms of; requirements, analysis, design, coding, testing, implementation and monitoring. They include the following;

i. Security and Data Retention- The application should not be able to access or collect users' private data without their knowledge and consent. A user may give their consent for some personal data to be collected for advertising purposes, but this should be a transparent process allowing users the option to refuse. It is crucial to limit the total volume of sensitive data that is linked to an identifier of the user.
   The application also needs to abide by the rules and regulations of the Application Stores they are disseminated.

Users rightly expect that after they close their account, all their data is essentially deleted from the application server, which is subjected to any legal retention limits. If the security of the app is breached, through hacking or any other means, the owner of the application is held responsible for failing to implement reasonable security procedures as well as for informing the users that their private data has been compromised.

ii. Enabling security measures- All applications that use, access or transfer data of any individual needs to be rigorously tested for different security purposes and comply with various current best security practices of security. It is imperative to implement data retention policies and security measures which will help in ensuring that the user data is rightly safeguarded. An application processing financial data is held to a higher standard by users than one not processing any sensitive information.

iii. Visibility and Timing- The privacy policy of the application should easily be accessible before a user downloads and registers on the application. Sufficient prior notice, choice or consent mechanism must be given to the users when the application wants to access sensitive information or data that might not be obvious to the average user. An explanation of the need to access that sensitive data should follow.

iv. Data Encryption- All vital or sensitive data, including passwords, credit card information and authentication information, must be encrypted to prevent access by unauthorised individuals.

v. De-linking and De-identification- Efforts to de-link and de-identify user data before sharing with third parties so that data cannot be linked to a particular user is imperative. This involves the scrubbing of different identifiable elements of the user's personal data, making it comparatively safe and enhancing privacy even when retaining the data for scientific or commercial value.

vi. Accountability and User Feedback- Users should be provided with a means to contact the application developers or owners who would respond to complaints, concerns and questions. This is also a good way for the development team to obtain user feedback and suggestions.

(DevTechnosys, 2016)

4. RESULTS

4.1. Technical and Functional requirements for the collection of Walkability-related data

Gyroscope and Accelerometer

These two sensory devices (with the addition of a compass) are combined to determine the position and absolute orientation, angles, yaw, pitch and roll of the device. The gyroscope uses earth's gravity to establish angular position based on the principle of the rigidity of space, comprising a freely rotating disk (rotor), mounted onto a spinning axis in the centre of a larger, and more stable wheel. As the axis turn, the rotor remains stationary to indicate the central gravitational pull, and thus which way is "down." (Innerd et al., 2015).

The accelerometer measures non-gravitational acceleration such that it responds to the vibrations created by the movement of the device from stationary to any velocity. They are of two types; microscopic piezoelectric crystals, and differential capacitance type, which can additionally sense rotation (Goodrich, 2013). In combination with the magnetometer, these sensors allow the phone to detect (kinetic) vibrations by calculating the amount of deviation from the gravitational pull. An application such as *Cheetah* incorporates an AI that continually learns from users' input on the cause of a particular vibration, so that next time there is a detection of a similar vibration, the phone automatically knows the cause of it.

Body-worn accelerometers can be equipped into smartwatches to provide objective measurements of physical activity. Most of these devices summarise the raw data collected into proprietary "counts" and could provide continuous acceleration data from which measures of physical activity could be derived using a range of algorithms. Traditional accelerometers summarise raw acceleration data into 'counts' and the computational methods used to calculate the counts depends on the acceleration of the device exceeding an empirically derived threshold value over a given time window or 'epoch'. Modern triaxial accelerometers do it more efficiently and make use of more advanced algorithms (Innerd, 2015).

Magnetometer/Compass and GPS

The magnetometer detects magnetic fields and compass heading relative to the earth's magnetic North pole. With GPS, it establishes the device's location. GPS, initially developed for military use, relies on satellites to determine location by connecting with multiple satellites then calculating where it is based on the angles of intersection (Forsblom, 2015). These devices are equipped onto mobile phones and other devices such as smartwatches, to map the location history of the user.

However, GPS is only accurate to within 9 m and is unreliable indoors. GPS dependency is an emerging phenomenon that opines that the over-reliance on GPS for mapping and navigation could alter the human brain in negative ways, particularly our natural wayfinding abilities and environmental awareness. This is because GPS mapping and navigation applications such as Google Maps, HERE Maps, and Waze, present directions in an egocentric perspective processed by the caudate nucleus, a part of the brain that responds to simple rewards (the place you are going is the reward). This egocentric perspective is a goal-oriented perspective that starts with you (your GPS position) and ends with your destination (Imagery Lab, 2018). It represents the location of objects in space relative to the body axes of the self (up-down, left-right, or front-back). The directions are therefore given to get you from Point A (your GPS location) to Point B, which is your destination.

Paper maps (and other sensory information for directions) on the other hand, present an allocentric perspective processed by the hippocampus, a part of the brain involved with complex thinking, like pondering the future (Imagery Lab, 2018). The allocentric perspective allows you to see the whole landscape (lakes, trees, roads, and hills) around you and you, therefore, have a more complex understanding in your mind of your place in the world rather than just a straight line. It encodes information about the location of an object in relation to other objects. This allows you to build a cognitive map in your brain, which gives you a much more robust understanding of the world and your place within it by sensing one's environment for barriers to travel, then navigating spatially to the destination. The two perspectives thereby use different neural networks in the brain and scientists are worried that the use of GPS navigation could make our brains to become more simplistic, stopping us from using the human brain's inherent evolutionally refined navigation abilities. Such applications, therefore, allow you to get to our destinations quicker, but we typically have a vague awareness of how to get there or the landmarks on the way (Imagery Lab, 2018).

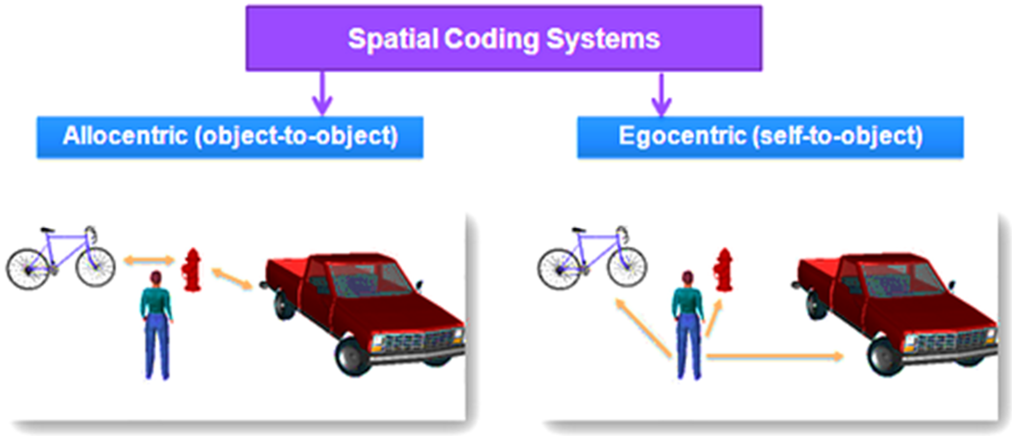


Fig. 4.1: Spatial Coding Systems

Proximity Sensor

This sensor is usually located at the top of the front side of the phone next to the front camera lens.

Fig. 4.2: Position of the proximity sensor

It comprises an infrared LED (Light-emitting diode) and an infrared light detector that establishes how close the device is to something else. This is done by monitoring the level of infrared radiation in the field of view of the sensor. On a mobile phone, it is typically used to decrease the display's power use by making the screen go out automatically, as soon as the device approaches the ear so that one does not accidentally push a button on the touchscreen, with their cheek or ear (Forsblom, 2015).

Ambient light sensor

The ambient light sensor is often located just next to the proximity sensor and is used to regulate the screen brightness in differently lit areas by determining the degree of outdoor lighting and adjusting the screen brightness accordingly. It does this to save energy, especially if one intends to optimise the consumption of their battery.

Barometer

This atmospheric sensor is available on more advanced mobile phones. To utilise it, the phone pulls down local weather information for a baseline figure of barometric pressure, but its accuracy is greatly affected by the conditions indoors, like heating or air-conditioning flows. They work best when utilised in conjunction with other tools such as GPS for location determination, Wi-Fi or cellphone data network to get weather base data from the internet, and beacons (Forsblom, 2015).

Pedometer

This device counts the number of steps walked by detecting the motion of the person's hands or hips. The accuracy varies and a simple calibration, performed by the user, is necessary since the size of every person's step varies. There are newer pedometers that use electronics and software to automatically determine how a person's step varies and have an accuracy of within ± 5% error.

Other sensors
The most modern smartphones also have a microphone, camera sensors for better photography, a fingerprint sensor for more secure access, website authentication and mobile payments. Newer models of smartphones even have an integrated heart rate monitor, step counter, and other health and physical activity detection tools.

Phone sensors are continually getting smaller, more accurate, less power-hungry, and more advanced, making the use-cases for these devices virtually endless. Less advanced phones "dumb phones", are being produced less, but are still widely in use, particularly in poorer countries in the global south. They could be configured to have more functionality, such as the ability to download applications and access the internet, but it is not an economically feasible nor future-proof venture (Forsblom, 2015). The various device sensors can serve to complement any faulty or low-quality sensor or how the device has been mounted.

The following functional requirements are necessary for the *Walkability* application;

i. Interface: The interface must allow for numeric data entry and allow for the on-screen printing of data to the printer. For the survey questions, it should only accept dates and times before the current date.
ii. Database: The database should have a functional audit trail, and for security purposes, the system should limit access only to authorised users. These authorised users would also have different permissions depending on their access levels. In order of increasing access levels, authorised users are classified as follows;

Fig. 4.3: Authorised users permission levels

Additional application features, strengths, system attributes and functional requirements are discussed later in Section 4.4.

4.2. Limitations of current transportation-focussed mobile phone devices and applications

Mobile phones come with their own inherent technical and functional constraints and limitations that affect the quality and usability of mobile applications, albeit, some of those limitations offer unique opportunities if adequately harnessed. As has already been stated, mobile phones currently available in the market have limited processing power to support Machine Learning and real-time AI and AR data processing on the devices. Instead, the information is collected by the device and sent to the cloud for processing. Cloud computing has the disadvantage that it can only be used reliably with a stable internet connection and data transmission would lead to significant delays. For some of these advanced analytics applications to work optimally on phones, it would require devices with tight integration of hardware and software, which is an advantage Apple IOS devices have over the widely-available Android devices.

Even though AI, AR, and Machine Learning integration into mobile devices is still in its infancy stages, it is likely that because different manufacturers such as Google, Apple, Lenovo, and Intel, are all competing, developing, and designing their systems and graphics and processor chips independently, the end products may not be cross-compatible or not compatible for different devices.

Other device hardware limitations include the following;

a). Specifications and accuracy of device sensors – The sensors of the various devices vary in terms of accuracy and strength/ability to detect even the smallest stimuli. The quality of results desired should determine the specifications of the sensors, but mobile phones are not custom made and mass-produced with these goals in mind. For example, GPS is unreliable indoors and is only accurate within 9m, which has implications for mapping, in terms of accurately tracing and positioning a moving target on the map. A pedestrian could be indicated on a map as being on the opposite side of the road rather than his actual position, which lies within the 9m margin of error of GPS devices.

b). Small screens – Mobile phones are small devices to facilitate convenience in carrying around. Compared to desktop and laptop computers, mobile phone screens allow for much less information to be displayed on them, and often one must zoom in an out constantly for better visibility. Mobile phone content is twice the difficulty of desktop computer content because users must incur a higher interaction cost to access the same amount of information and depend more on their short-term memory to refer to information that is not visible on the screen. To include new design content or elements on a mobile phone screen, some other content would likely be edged out of its original position on the screen; hence developers must always consider feature and content prioritisation, and the opportunity cost of adding new content or making changes (Budiu, 2015). Because of the small screens, users typically view one window at a time, and it is impractical to split the screen into multiple screens like on desktop computers.

c). Portability- Because of mobile phones being easily portable, attention is often fragmented, and according to various studies, sessions on mobile devices are short, with an average mobile session being 72 seconds long, compared to twice as long, 150 seconds, on a desktop. Mobile application developers must prioritise the essential and simplifying tasks and interactions and must design for interruptions by making it easy for users to recover context and resume an interrupted task without having to redo work. "*The gist should always come before the minutiae"* (Budiu, 2015).

d.) Touch Screens – It is difficult to type proficiently on the limited screen sizes, which are prone to accidental touches. The type-pad is displayed on the screen and therefore takes the already diminished display space for content.

e). Limited Battery capacities – The battery sizes of most of the mobile devices available in the market are limiting because advanced functionality like AR and processing speeds consume significant amounts of battery power and limit the durability of these batteries. The types of batteries standard in the market are lithium-ion (Li-ion) batteries which degrade and last on average up to 1000 cycles which is the number of full charge-discharge cycles before significant capacity loss. They work by having lithium ions move from the negative electrode to the positive electrode during discharge and back when charging.

4.3. Testing and Feedback mechanisms

When developing the application and testing how well it works, the following are the key factors that had to be considered:

- Who are the expected users;
- The functionality required;
- Type of experience the users expect;
- The need for multi-platform compatibility depending on the characteristics of the likely user base;
- Need for offline usage or low-data usage requirements;
- Industry-specific requirements;
- Time constraints (how long it would take to develop each feature and how much time was available);
- Financial constraints (cost of developing each feature);
- Technical expertise requirements (capability and experience).

The application and functionalities added were tested based on the systematic procedure described in Chapter 2 of this report. These features are further elaborated on in Section 4.4. The application testing and feedback mechanism was managed and facilitated using a web-based Git-repository manager called GitLab that provides issue tracking, wikis, database management, code review, and allows for team collaboration (between the development team and alpha and beta testers). The alpha and beta testing of the application took 7 months and focussed on the following aspects:

i. Login and authentication (GitLab and dashboard)
ii. Feedback mechanism: Create issue using users' credential and not as an administrator. The application should be able to send email confirmations once one submits feedback and when their issue/bug is fixed
iii. Location Updates, especially with the GPS settings for GPS Only, Network, and High Accuracy modes
iv. Routing Data and Offline Maps
v. Store the Assessment Data to the server which can then be viewed on the online Dashboard
vi. The User interface (should be easy to navigate and aesthetically appealing)

Feedback in the application could be provided using images, videos, voice notes, and text notes. The user can annotate the screen with comments as well as attach supporting media and information. Upon first launch of the application the user is prompted to login with his/her

Google account, after which a GitLab Google authentication can be used for any feedback activity so that the user feedback is registered to their name, and users can track the interactions with the developers on any open/closed issues they initiated. With every feedback or error reporting, the user received an email or SMS (push notification service) for tracking purposes and follow-up correspondence. Additional details and the screen dumps are presented in **Appendix C**.

Throughout the testing period, various kinks and bugs were identified, corrected and re-tested. Many of the minor bugs were due to the type of device used, the operating system, the chipset type, the display resolution, the amount of memory required (RAM), device manufacturer OEM customisations, and the range and quality of the device sensors. Some of the more persistent and more critical issues identified included the following;

i. Map view not rendering- The Map view at times was no longer visible on either the feedback screen and when walking. There was no map display on trips and nowhere on the screen to toggle the map view on/off. This issue was fixed by setting the GPS to "High Accuracy" mode and manually adding the downloaded maps to the application files directory. After doing this, the application would be restarted. Track lines were also added on maps when walking.

ii. Offline maps being unavailable- The offline map and routing data previously downloaded did not carry over to later versions of the application. This was confirmed by turning off Wi-Fi and data connection and checking whether the device was able to detect any map or routing data already present on the phone. This issue was fixed by re-establishing the connection to Ramani Maps API and downloading the offline maps from there.

iii. Random screen freezes and crashes, particularly after uploading assessments. This issue was fixed by restarting the application after GPS had already been turned on before opening the app, instead of turning GPS on while in the application. Also, turning on the GPS from the application, caused a response lag, but this was a device defect rather than an application one.

iv. The pedometer/distance counter was slow to respond such that one would walk for a couple of minutes outdoors, both on-street and off-street, but the counter remained at 0 m. It then changed abruptly after about 30 minutes. It would thus be impossible to tell how far one had walked. The stated GPS accuracy setting "High Accuracy" also produced jumps along a route and was very unstable. The meter count increased by 1000 m almost every second. Sometimes it stabilised and increased in instalments, but the result on the dashboard would still record jumps. This issue was fixed by employing multiple access to the location for increased accuracy through;

- Low accuracy mode (GPS-based or mobile network-based)
- Battery Saving approximate location (Wi-Fi and mobile network-based)
- High accuracy precise location (GPS, Wi-Fi, and mobile network-based)
- Extra location information provided by the user

v. Triggers not being activated after every 100-150m. Once the pedometer issue was fixed, this connected issue was corrected automatically.

vi. No triggers notifying users to provide feedback after every 100 m or so. This functionality was added and tested.

vii. Inability to download offline maps and routing data because the download button is greyed out (for all the countries). This issue was easily fixed in the application code.

viii. Some of the screens at times did not allow for information input such that one could not type their responses below each question. This issue was fixed in the application code.

ix. Duplication of the location marker. This issue was fixed in the application code.

4.4. Walkability application feature list

Current technological practicalities, user requirements, financial resources, human resources, and the needs for mobility, informed the features and functionalities implemented into the application and those to be focussed on in future as part of the research and development (R&D) phase. The following sections will outline these functionalities.

Contextual triggers not to over or under-ask the respondents (in citizen science applications), would be implemented to tackle the challenge of interview fatigue. These contextual triggers, which trigger actions based on context, are essential such that at the right moment and in the right amount, the respondents are asked for their opinion. These triggers are based on the smartphone's sensors, which ensure the triggers occur at the precise moment. For example, when the application detects that one is stopping or slowing down at an intersection (the contextual parameter), the respondent should automatically be triggered by the application, to provide information on whether the traffic light is still working. This typical use case is illustrated later in this chapter. The contextual triggers can then be coupled with transition triggers which operate when you transition from one place to another, for instance, "Upload data to the server when I arrive home (a geographical location)".

From a data collection perspective, considering that a question on an aspect (such as a traffic light) has for instance, already been asked and answered 10 times (by 10 different respondents), there is no need to ask it an eleventh time to someone else because the data for that aspect is already enough. This is because the non-parametric and parametric statistical tests have their specific sample size requirements, and once these requirements are met, the application can intuitively stop asking the respondents to provide more of that information. In this way, different users would be providing data on different segments of the study area. The application has sufficient robustness in finding the uncertainty and separating signal from noise. Robustness refers to the insensitivity of statistical criteria to changes of a magnitude, likely to occur in practice, in extraneous factors.

A typical use case for this application is a person walking past an intersection. The application can detect the location of the user and ask the user any number of questions based on where he/she is. This location information is provided by Open Streets Maps (OSM) which is a collaborative project founded in 2004 to create a free editable map of the world and has grown to over 2 million registered users, who collect data using manual surveys, GPS devices, aerial photography, and other free sources. The crowdsourced data is then made publicly and freely available. The data quality, however, varies for different places around the world, depending on how much information has been provided of a location by users; naturally, some locations are better represented than others. It is already used by many popular applications and services such as *Craigslist, Flickr, Apple iPhone iOS, Wikipedia, Moovit, Tableau, and Snapchat*.

The open-source freely available Open Streets Maps that is used by this application contains the following relevant data;

- street widths
- Traffic levels
- Cleanliness reports
- Gradients
- Crime statistics (safety of routes)
- Pedestrian accident statistics
- Number of trees on a street

This interaction is illustrated in Figure 4.4, whereby the application triggers the user to respond to whether the intersection is signal-controlled and whether the markings on the crossing ahead are still visible. In this instance, the application can detect using GPS that the user is crossing the Mara/Ragati junction in UpperHill area of Nairobi. The user only needs to tap “Yes” or “No” on their screen. They can opt to provide additional information at that moment or later. The range of questions that can be triggered is discussed later in Table 4-3 in Section 4.6 of this report.

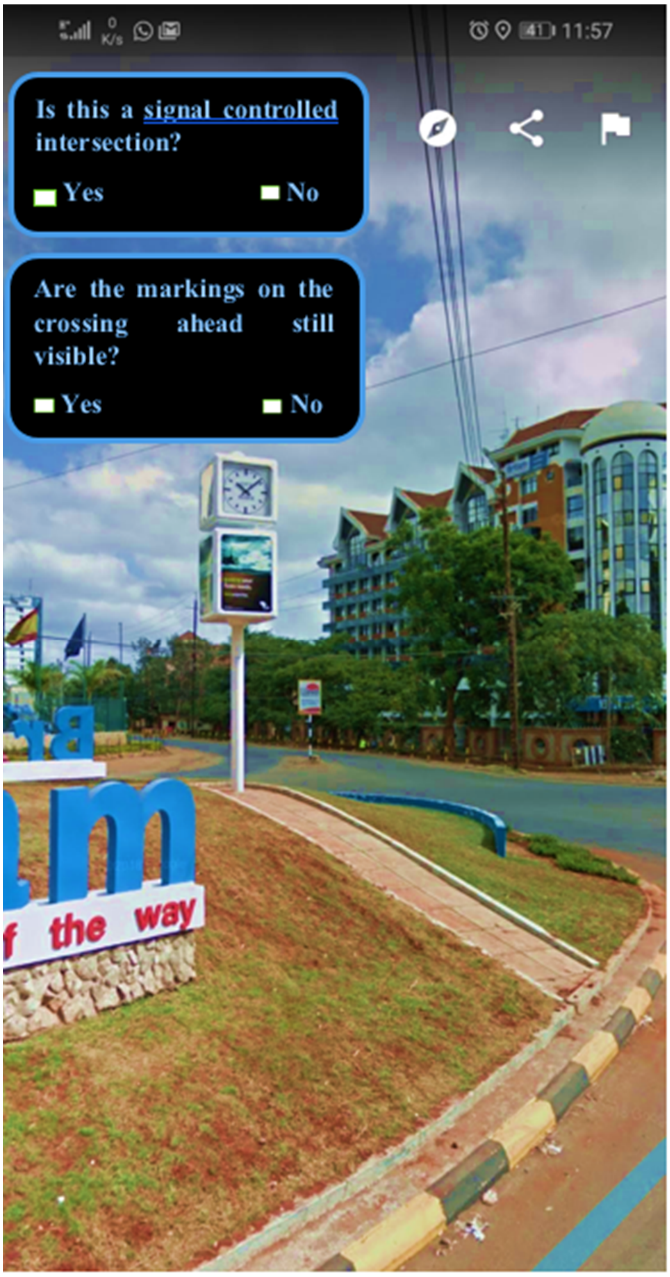
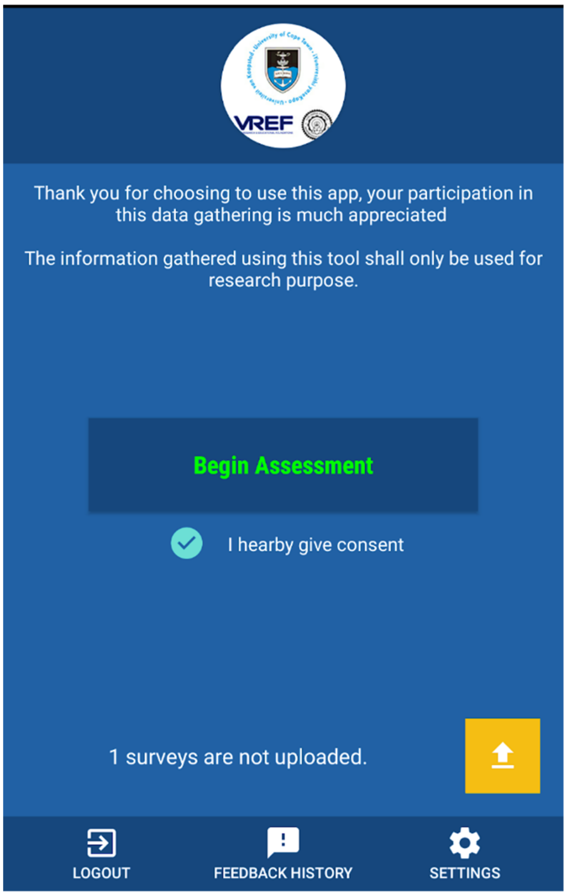


Fig. 4.4: Sample triggered question for a sample use case

The ability to personalise the application by saving preferences, showing their history, filtering results, and customising the appearance and UIX (user interface and user experience) of the application makes users more emotionally attached to an application over the long term. The UIX design factors in the needs, abilities, and limitations of the potential users, to provide them with a premium and enjoyable interaction with the application and positive perceptions of the service and offerings. This also applies to the desktop-based tools with graphical UIX interfaces. Furthermore, the User Interface incorporates more swiping actions and pictures allowing users to tap to choose between two or more pictures, instead of having to manually key-in their responses. This reduces the time users spend interacting with the phone preventing user fatigue. Ease of navigation in the application interface is key because people struggle to embrace applications if they need to put unnecessary time and effort into them just to get started.



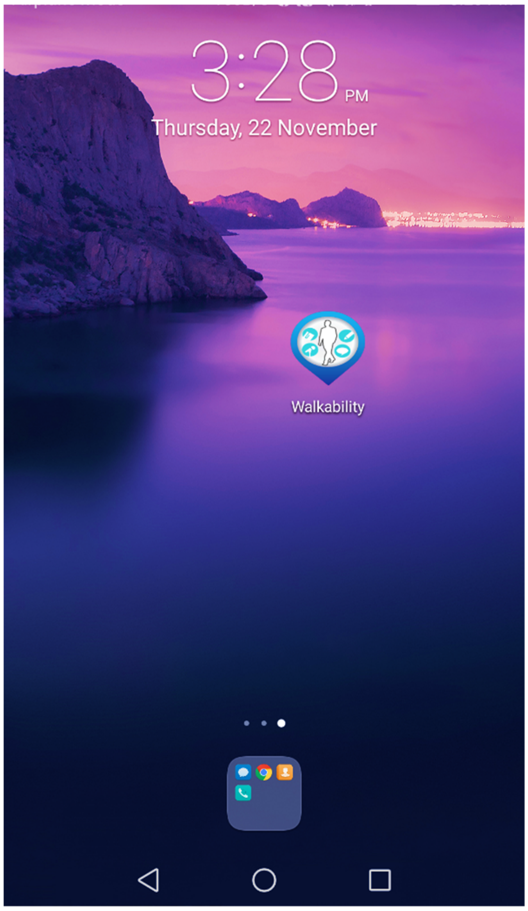
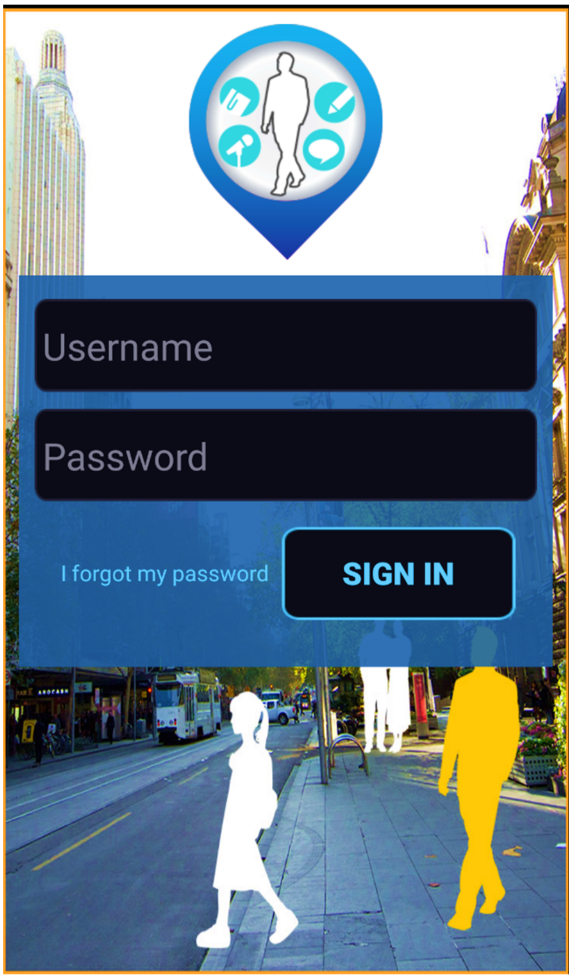


Fig. 4.5: Privacy consent screen

Fig. 4.6: Application icon

It is widely accepted that respondents prefer autonomy in using an application. The application will be perceived as more tailored to users' needs and users want to remain in control of what data the application is accessing and how that data is used. Anonymity must always be maintained, and under the control of the respondent in terms of how much information they are willing to share and how that information is utilised. The first step taken is to ensure anonymity by making sure that the data cannot be easily connected to the specific person it came from. This is done by not including people's names or other unique, identifying personal information. An additional measure is making sure that there are at least two or more respondents that have the same characteristics so that they are indistinguishable from each other, which helps keep the data private. This is a concept in statistics called K-Anonymity where K is the number of subjects who share the same characteristics, therefore the larger the K, the better for anonymity. As demonstrated in Figure 4.5, this *Walkability* application seeks users consent before collecting any information and informs the user of the purpose and use of the information they provide.



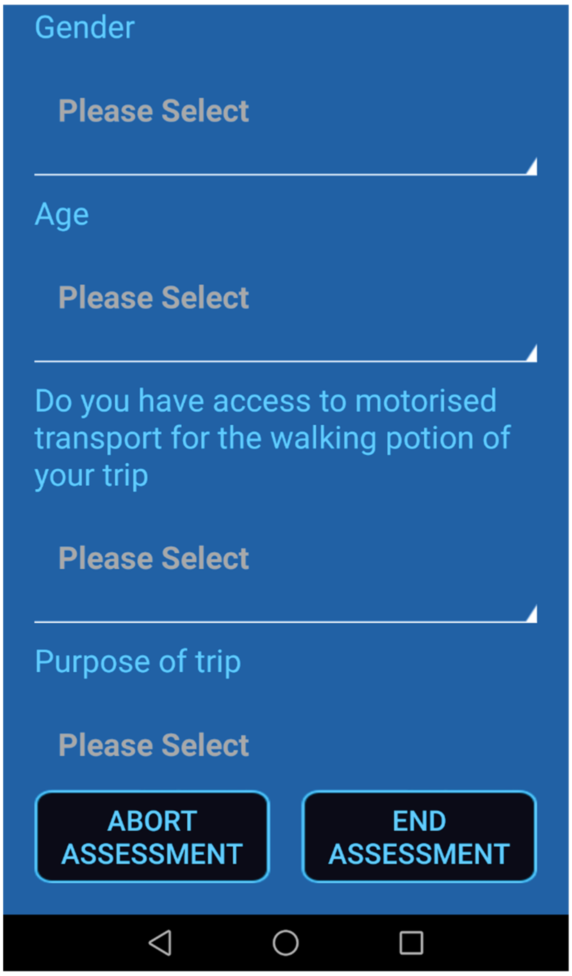


Fig. 4.7: Registration and Account Setup **Fig. 4.8: Demographic information**

When signing up to the application, users will be asked to register an account using their email address or social media account. Demographic data will then be asked including their age and gender, as shown in Figure 4.8. All application to server communication is securely transmitted using state-of-the-art 256-bit SSL-encryption, and all data is always kept anonymous by having no IP-address logging or user ID-tagging that could identify individual users or link them to their responses.

The application would need the following additional permissions to be granted on the phone by the user;

i. Location
ii. read phone status and identity (Device ID)
iii. Photos/Media/Files: read, modify or delete the contents of the USB storage
iv. Storage: read, modify or delete the contents of the USB storage
v. Camera: take pictures and videos
vi. Microphone: record audio
vii. Wi-Fi connection information: view and connect to Wi-Fi connections
viii. Other: disable screen lock, full network access, control vibration, prevent the device from sleeping, and modify system settings.

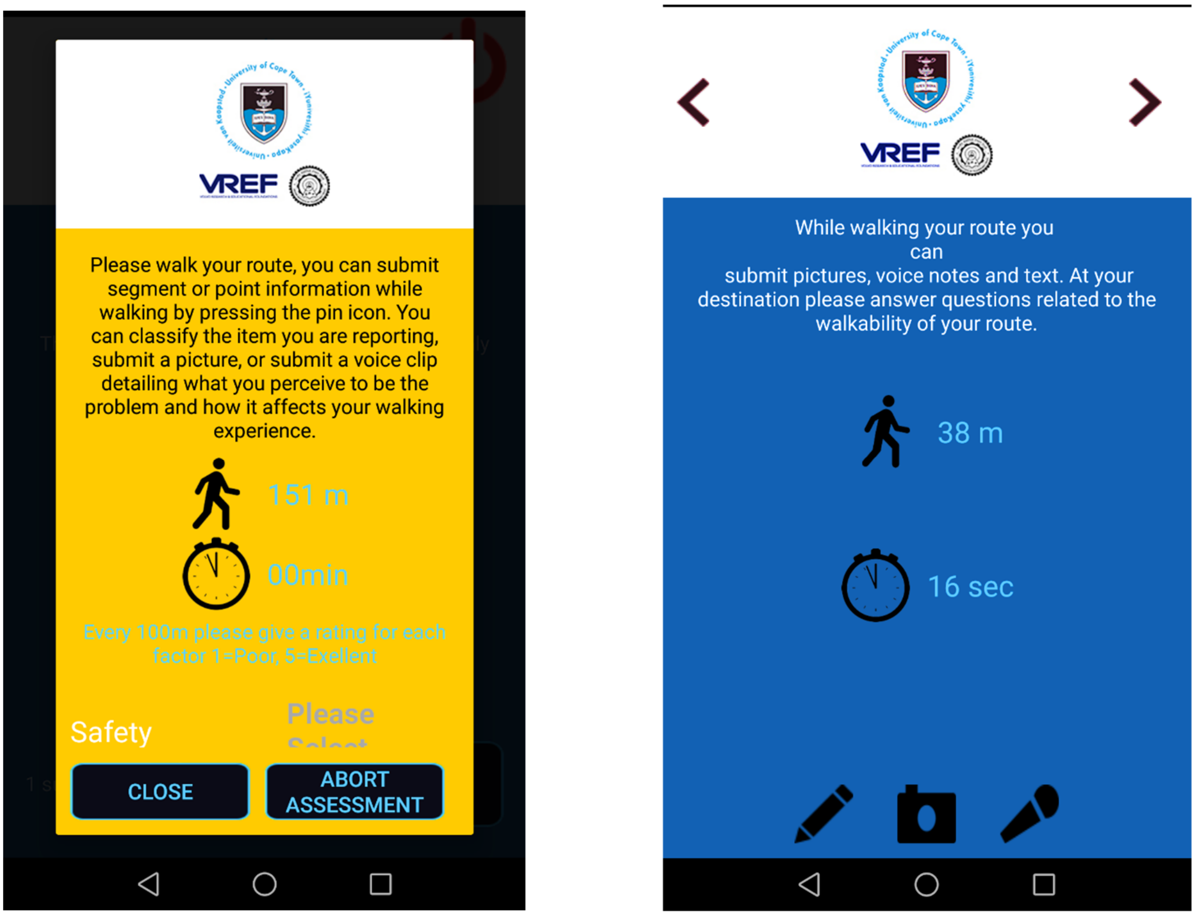


Fig. 4.9: Step by step user guides

Table 4-1 summarises the features already implemented and those that could be considered in the future.

Table 4-1: Application Feature list and future functionality (with timeframes)

Nice to have features and functionality (in future)	**Must have features and functionality (already implemented in application)**
Voice Assistant to reduce manual interaction with the application and prevent respondent fatigue Easy to implement and test (<1 month)	Augmented Reality- For visualisation of pedestrian object-information. The AR overlay on top of the camera view will be transparent on the screen for safety reasons to allow users to see obstacles in their path. This was a complicated feature to implement and test and took seven months to implement. It still requires further testing and improvements.
Show your CO_2 footprint and savings made by walking	Crowdsourcing- Because this is a crowd-sourcing application, all data comes from the users through direct observations from photos

Easy to implement and test (<1 month)	and videos. The human eye is therefore used as a sensor. An author-reviewer-publisher workflow will facilitate all incoming observations and comments to be aggregated and analysed, for example, using nonparametric statistics for turning raw observations and user opinions into useful information
Basics including; a) Weather- to show what the weather conditions were when the infrastructure audit by the user was provided b) Social media integration c) Torch/flashlight functionality for multi-purpose use and visibility at night d) Calendar Easy to implement and test (<1 month)	Maps API- The RAMANI Maps-API adds map data (including weather data and other satellite information) to the application and automatically handles access to the map servers, returning retina optimised tiled map displays. It provides a variety of charts as PNG-images or Scalable Vector Graphics (SVG) for further client-side interactions and use of satellite data. It also deals with the inherent uncertainty in location accuracy because of poor geolocation provisioning, which is typical for most low-cost smartphones. This is done by using a ‘snap-to-road’ process, whereby the GPS-fix reported by the device is instead snapped onto the nearest infrastructure, for instance, a road or pedestrian track, which is then used instead, as illustrated in Figure 4.12. This can be done using offline, vector-based background maps from Open Street Map (OSM), which provides the infrastructure (coordinates) to snap to. The coordinate reported by the smartphone’s GPS is thereby snapped to the roads’ infrastructure provided by OSM. Missing roads can also be contributed to OSM in an author-review publishing workflow and to ensure snap-to road functions in areas still requiring substantial mapping.

3D Maps- Easier to visualise Easy to implement and test (<1 month)	Map View and AR view. The map displays are scaled to pedestrians and not vehicles. By default, the map-view is only shown when adding an ancillary asset (such as a photo or video on the map), rather than being always present. It can also be toggled on and off depending on the users' preference. The map view is illustrated in Figure 4.10.
0-5-star Likert rating system Show each streets' rating on a colour-coded map layout. Also, can find the fastest high/low star route to any destinations. Filter routes based on: a) Most scenic b) Most direct/ Fastest c) Route with most natural or physical features, including parks, bathrooms, et cetera. d) Pet-friendly route e) Hiking routes- Least hilly/physically demanding route (low gradients) f) Routes with good phone network coverage or Wi-Fi coverage g) Location scouting for film production Relatively easy to implement and test (3 months)	Offline Maps and offline use- The data then synchronises to the cloud when the user goes online (Figure 4.11)
Points of interest- With pictures, information and an events calendar Easy to implement and test (<1 month)	Update service- To keep the application up to date with new features and bug fixes
Show users how the information they have provided has helped other users. For example, "Thanks to your submission on the traffic light conditions on Entebbe Road, 200 users adjusted their commutes to include this road." Easy to implement and test (<1 month)	Multiple access to the location for increased accuracy through; a) Low accuracy mode (GPS-based or mobile network-based) b) Battery Saving approximate location (Wi-Fi and mobile network-based)

	c) High accuracy precise location (GPS, Wi-Fi, and mobile network-based) d) extra location information provided by the user
Panic button that when triggered (either by pressing a pre-determined number multiple times, shaking the phone, tapping an SOS button, or any other methods), instantly and quietly calls, texts, or sends a notification to one's emergency contacts that contains their exact real-time location. - Easy to implement and test (<1 month) This feature is to protect users providing data on new paths or in the evening	Geo-tagged photos and videos- For the easy location of objects
Machine Learning (Supervised, Unsupervised and Semi-supervised)- Difficult to implement (9 months)	Web interface for results reporting, trend analysis, and visualisation through an online Content Management System
Cross-platform compatibility and works on most mobile browser- (2 months to implement)	Error reporting and feedback tool. The error reporting functionality has been designed such that at any instant, users can submit feedback on their app experience through a feedback form. It allows the user to annotate and draw on the screenshot taken for enhanced clarity. Once the user submits the feedback, a confirmation e-mail or SMS (push notification service) is sent back to the user for tracking purposes and follow-up correspondence
Social media integration and communication with social networking APIs -Easy to implement and test (<1 month)	Step by step training video and manual when the application is launched for the first time. Most users would not need the training as the application is easy to use and guides the users at every stage of the process
Gamification- Easy to implement and test (<1 month)	Login and Authentication mechanisms to authorise the usage of the application

	If voice interaction is encumbered or difficult, say because of background noise from traffic, a surface overlay with questions at the top of the screen will appear, as an alternative input method. Furthermore, these questions can be sourced from a database which is accessible by clients allowing them to edit the questions to fit their intended purpose.
	Storage of data locally while displaying total statistics for the user
	Pedometer- Steps and distance counter

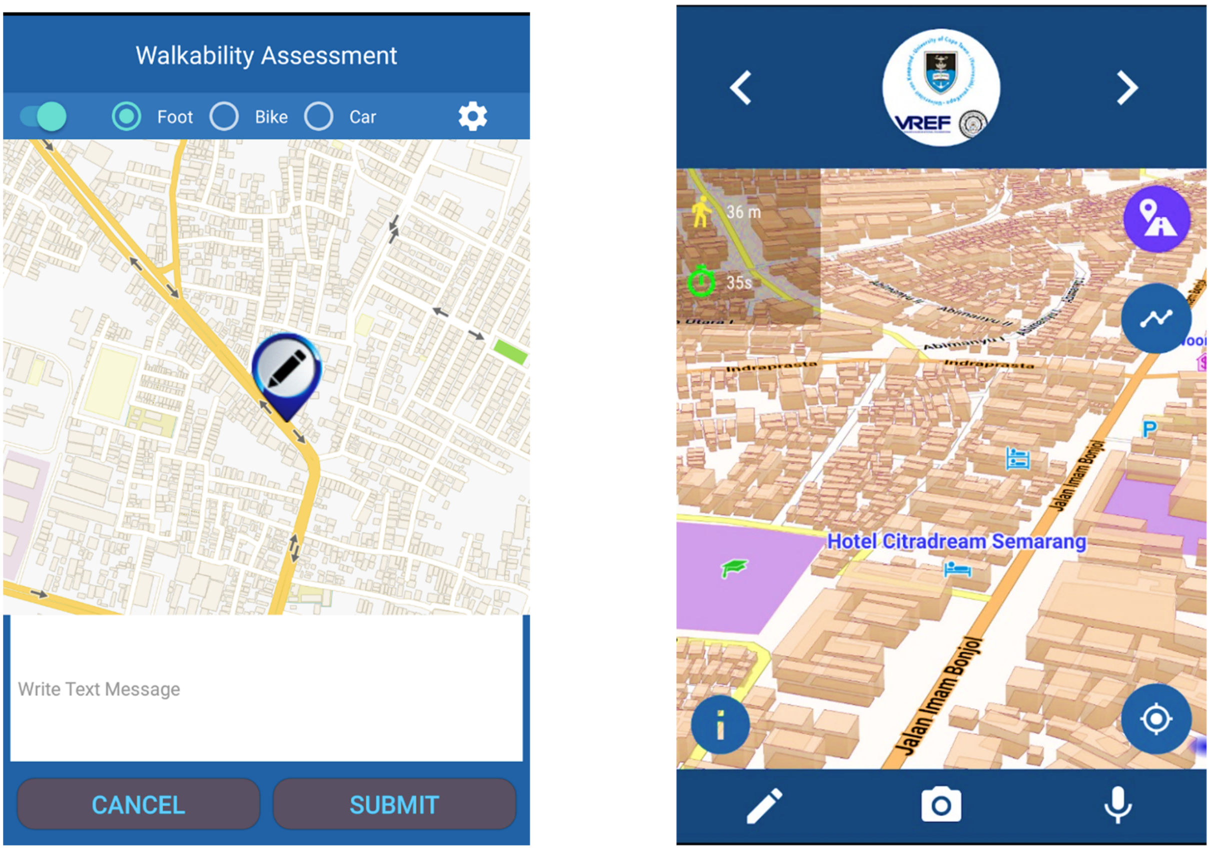


Fig. 4.10: Map view and 3D Visualisation of walking surroundings

All the collected data synchronises automatically to the online server (Cloud) when the device is connected to the internet. When not connected, the information is stored locally on the device memory until when a connection with the server is established. Offline maps and routing data are also stored on the device storage to allow for use without an active internet connection. The offline maps and routing data are downloaded ahead of time and remains available indefinitely or until it is updated to a later version. Due to its size, the download can be paused and resumed at a later time or when one is connected to Wi-Fi to save on data costs. Figure 4.11 illustrates this.

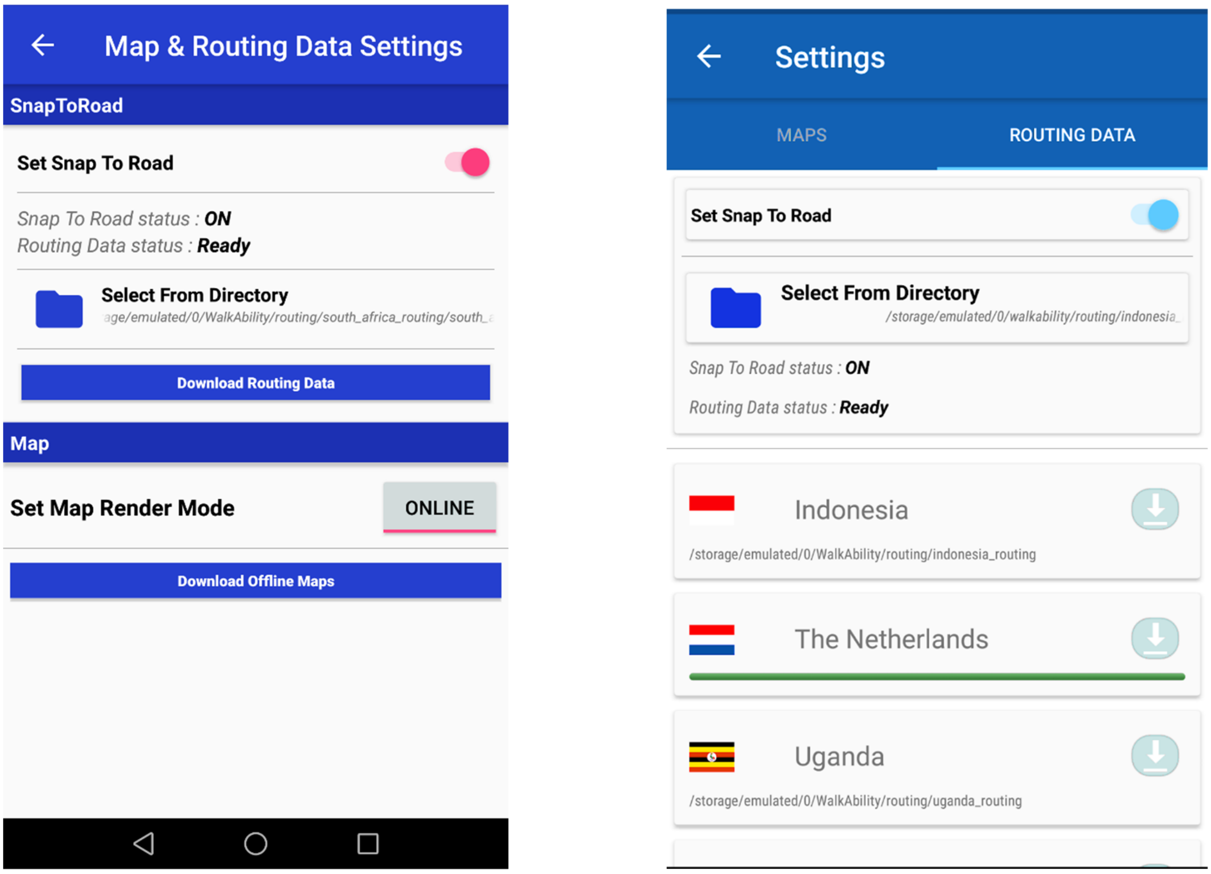


Fig. 4.11: Routing data and maps available offline

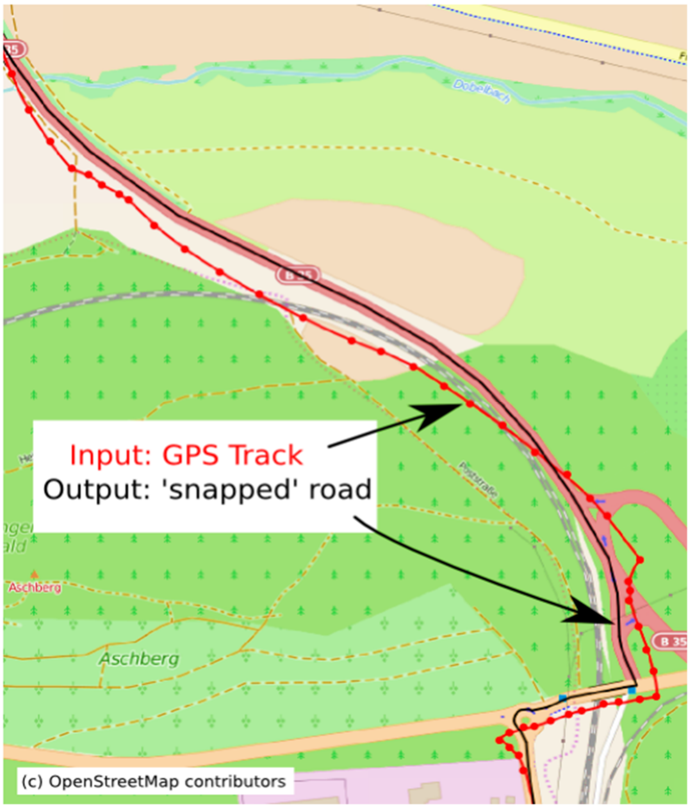


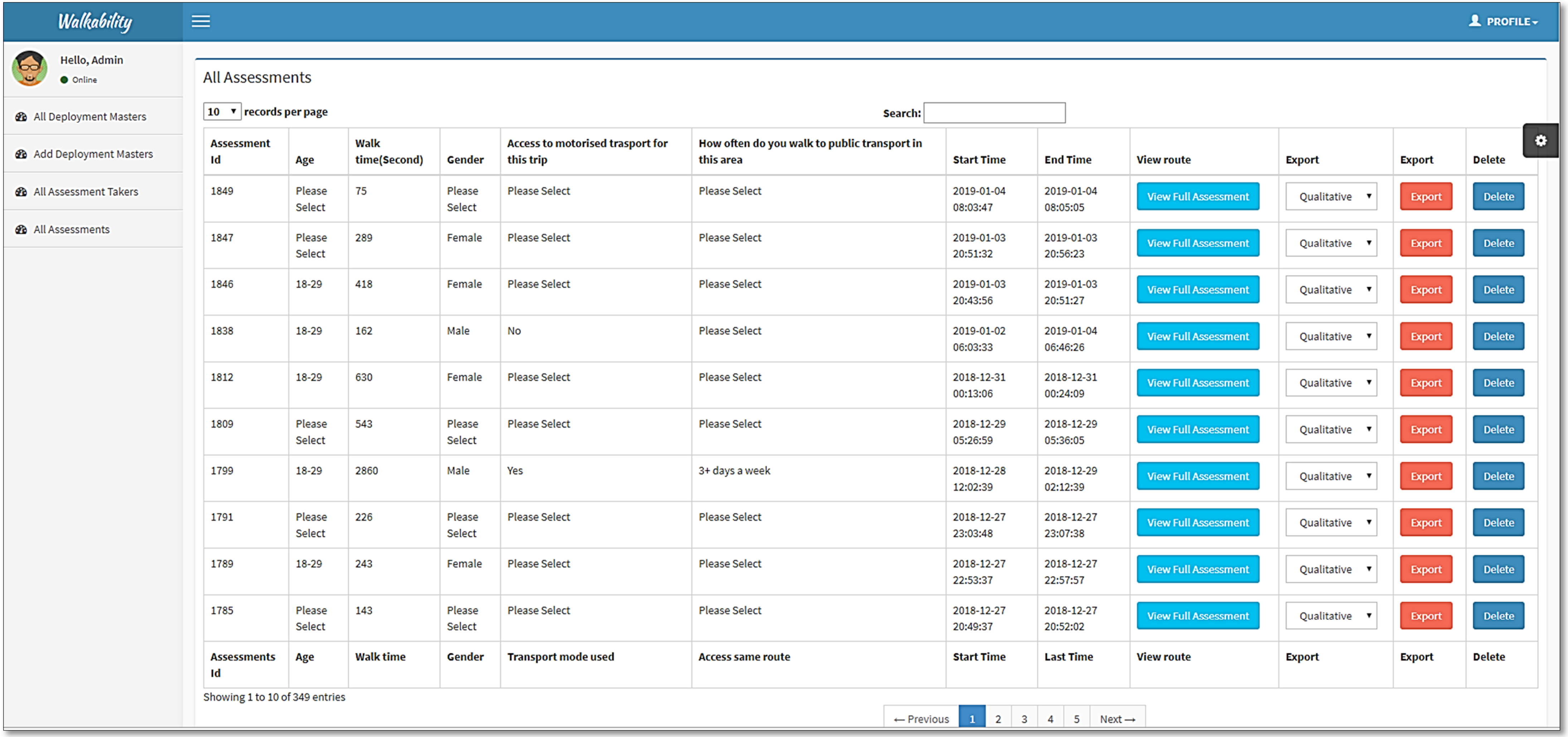
Fig. 4.12: Snap-to-road functionality on the Walkability application

The users use their smartphones to take pictures of the features, and the geographical location where the picture was taken is embedded into the photo's metadata. This location information from all the users can then be displayed on a map within the photo application on the phone as well as in freely available photo organisation software for computers. Alongside these photos were notes, annotations, and wayfinding markers the users inputted into their pictures to add additional information. When this information is compiled, it can show a range of maps and diagrams that illustrate a lot of useful information.

Once the data has been collected and analysed by the application, it is then curated and visualised at a central location in the form of a web dashboard (accessible on computers and mobile phones) as illustrated in the figures below. The User logs in to the system and depending on the permissions assigned to them by the **Owner/Admin** (administrator), they can view the (anonymised) data collected, i.e. user responses. Only the Admin(s) can view, or delete all files by default (including id, email, phone number, username, password and deployment area), and add other admins. All assessments reports are synchronised with the *Walkability Cloud* and can be analysed and assessed for trends in reporting. This data can then be downloaded in convenient formats including text and audio formats (MP3), Microsoft Excel and CSV (Comma-separated values) which are simple file format used to store tabular data, such as spreadsheets or databases (illustrated in Figure 4.13).

Figure 4.15 illustrates how the Admin sees an overview of all the submitted qualitative and quantitative user responses.

(Additional User Interface images are available in Appendix C).



All Assessments

10 records per page   Search:

Assessment Id	Age	Walk time(Second)	Gender	Access to motorised trasport for this trip	How often do you walk to public transport in this area	Start Time	End Time	View route	Export	Export	Delete
1849	Please Select	75	Please Select	Please Select	Please Select	2019-01-04 08:03:47	2019-01-04 08:05:05	View Full Assessment	Qualitative	Export	Delete
1847	Please Select	289	Female	Please Select	Please Select	2019-01-03 20:51:32	2019-01-03 20:56:23	View Full Assessment	Qualitative	Export	Delete
1846	18-29	418	Female	Please Select	Please Select	2019-01-03 20:43:56	2019-01-03 20:51:27	View Full Assessment	Qualitative	Export	Delete
1838	18-29	162	Male	No	Please Select	2019-01-02 06:03:33	2019-01-04 06:46:26	View Full Assessment	Qualitative	Export	Delete
1812	18-29	630	Female	Please Select	Please Select	2018-12-31 00:13:06	2018-12-31 00:24:09	View Full Assessment	Qualitative	Export	Delete
1809	Please Select	543	Please Select	Please Select	Please Select	2018-12-29 05:26:59	2018-12-29 05:36:05	View Full Assessment	Qualitative	Export	Delete
1799	18-29	2860	Male	Yes	3+ days a week	2018-12-28 12:02:39	2018-12-29 02:12:39	View Full Assessment	Qualitative	Export	Delete
1791	Please Select	226	Please Select	Please Select	Please Select	2018-12-27 23:03:48	2018-12-27 23:07:38	View Full Assessment	Qualitative	Export	Delete
1789	18-29	243	Female	Please Select	Please Select	2018-12-27 22:53:37	2018-12-27 22:57:57	View Full Assessment	Qualitative	Export	Delete
1785	Please Select	143	Please Select	Please Select	Please Select	2018-12-27 20:49:37	2018-12-27 20:52:02	View Full Assessment	Qualitative	Export	Delete
Assessments Id	Age	Walk time	Gender	Transport mode used	Access same route	Start Time	Last Time	View route	Export	Export	Delete

Showing 1 to 10 of 349 entries

← Previous 1 2 3 4 5 Next →

Fig. 4.13: Dashboard information (downloadable in convenient file and audio formats

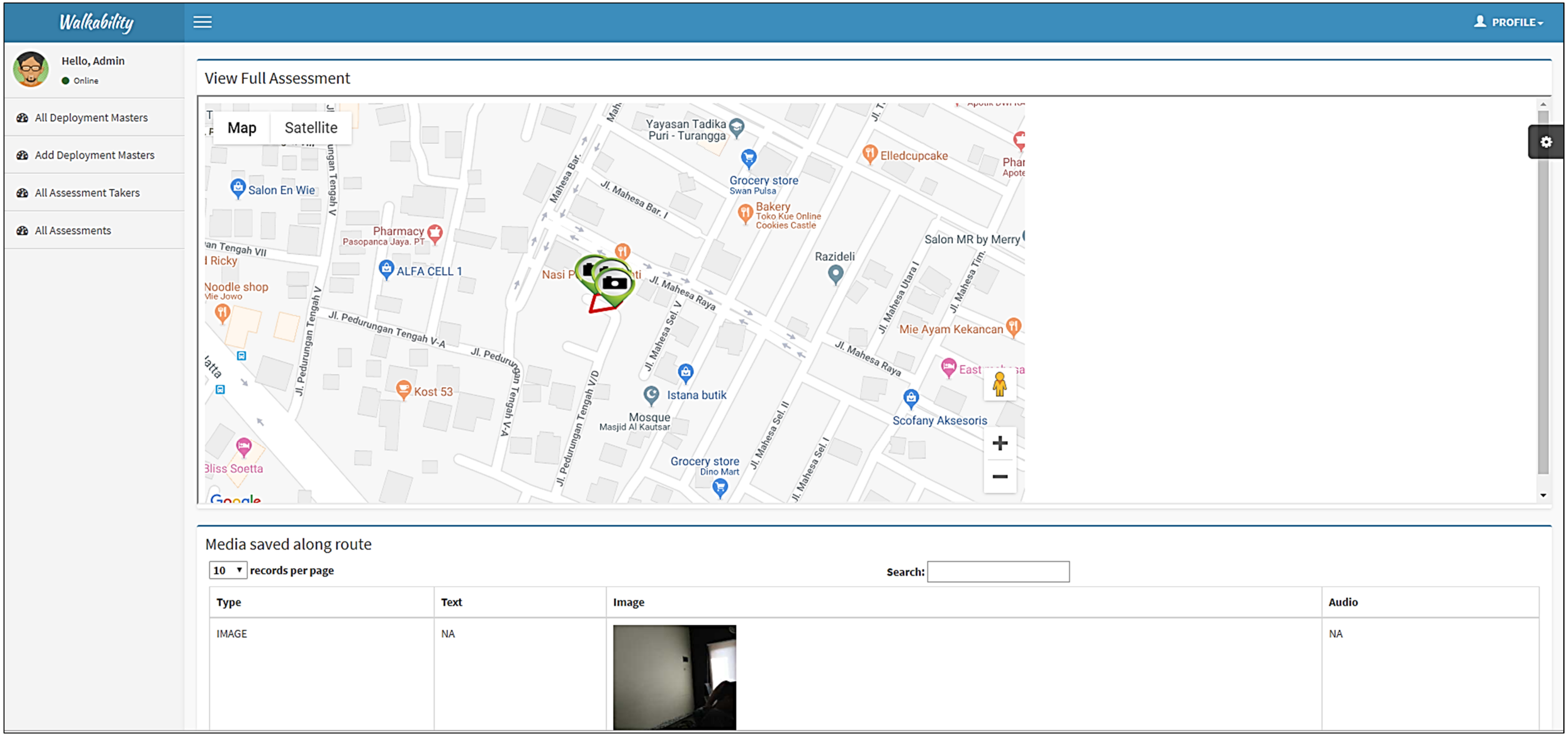


Fig. 4.14: Overview of incident locations and submitted images and voice recordings

Media saved along route

10 records per page

Search:

Type	Text	Image	Audio
AUDIO	NA	NA	0:00 / 0:13
IMAGE	NA		NA
IMAGE	NA		NA
TEXT	bad road quality here	NA	NA

Showing 1 to 4 of 4 entries

← Previous 1 Next →

Qualitative 1

KEY	VALUE	TEXT
1. Rate the cleanliness and maintenance of your walking environment	3. Moderate	
2. Rate the provision of non-residential uses and retail activities	2. Low	
3. Rate the degree of obstruction along the route	2. Low	
4. Rate the provision of pedestrian oriented amenities such as dustbins and public seating along the route	3. Moderate	
5. Rate the amount of tree-lined shade cover along the route	4. High	

Qualitative 2

KEY	VALUE	TEXT
1. Rate the provision of safe crossings along your route e.g. zebra crossings/ pedestrian malls/signalized intersections	4. High	
2. Rate your sense of safety from injury caused by motorised transport	3. Moderate	
3. Give a rating for the amount of moving motorised transport along your walking route	3. Moderate	
4. Give a rating of how you perceive the speeds of motorised transport along your route	Please Select	

Qualitative 3

KEY	VALUE	TEXT
1. How much pedestrian oriented lighting is available along your route	3. Moderate	
2. Rate the level of human activity along the streets that make up your route	4. High	
3. Rate your sense of personal security while walking along your route	4. High	

Qualitative 4

KEY	VALUE	TEXT
1. Rate the quality of pavement material	3. Moderate	
[illegible]	[illegible]	

Fig. 4.15: Overview of qualitative and quantitative user responses

Too many features can, however, be distracting, and confusing—obscuring the principal purpose of any application. On the flip side, innovation and developing new features is crucial to sustaining interest in an application over time. Users favour applications that can be integrated within the user's wider technology (or life) ecosystem through applications utilising existing phone features (calendar, and camera) or applications working seamlessly with their other applications and devices (voice assistants like Siri, smartwatches, and so forth).

Because of time limitations, some features could not be incorporated into this prototype application because of the amount of time required to test them in the field comprehensively. The detailed timelines for the "nice to have" features (in future) is as outlined below;

i. The implementation of the online GeoICT backend, and App-based frontend integrating AR, ML, and crowdsourcing technologies to observe and report on the walkability of paths used by pedestrians to reach points of interest- 3 months
ii. Calibration of algorithms for location aware-triggers to prevent under or over-asking user responses- 1 month
iii. Technical report on the results of the first field trials, the sufficiency of the on-screen Tutorial and entire User Interface- 1 month
iv. Technical report on the validation of algorithms for location aware-triggers- 2 months
v. Updated release of online GeoICT backend, and App-based frontend integrating AR, ML, and crowdsourcing technologies based on feedback from the first trials- 2 months
vi. Author-reviewer-publisher workflow implemented to facilitate all incoming observations and opinions to be checked, corrected and analysed- 1 month
vii. Expanded backend to perform geo-analytics on the crowdsourced data- <1 month
viii. Infographics engine developed turning raw observations and user opinions into information for all different end-users- <1 month

In addition to the above, incorporating gamification, which is the process of game-thinking and game mechanics to engage users and solve problems, could be considered at a later stage in the application. Interestingly, mobile games provide more revenue than other mobile applications primarily because the users are driven by the inherent joy (from dopamine release in the human brain) that the act of playing provides, rather than for real-world tangible rewards. Points and badges rewarding users with status can be awarded as indicators of achievement levels (mastery of the game) and progress. These could later be redeemed for monetary rewards or free items as part of a loyalty scheme and serving to align respondents to shared goals while acting as virtual status symbols. A leaderboard would create a competitive environment framing application engagement as a competitive pursuit that motivates users. Gamification is however not a silver bullet to get users to engage with an application; rather, respondents must already be intrinsically motivated to engage with the application which fulfils a core need for them. This aspect is further discussed in section 4.5.

4.5. User motivation and Application Monetization

Since this application will employ the use of contextual triggers, it is vital to understand how this affects the users' behaviour, motivation to keep using the application, and even recruit other users. The Fogg behavioural model visualises how ability, triggers, and motivation, all contribute to the likelihood of a given behaviour occurring. When a behaviour does not occur, at least one of those three elements is missing.

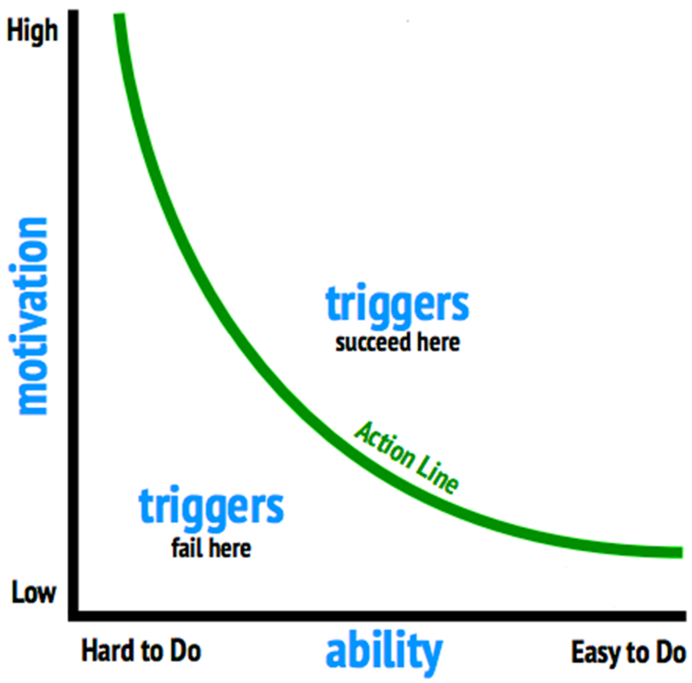


Fig. 4.16: The Fogg Behaviour Model

(Adapted from Lusby, 2017)

According to the Fogg model, to facilitate user engagement, the application must achieve the following;

- Be **simple** to use, by reducing or removing barriers that discourage use, and simplifying the decision making for the respondent by having easily comprehensible benefits. This is because every decision leverages one's resources in terms of their time, money and cognitive load, against the potential rewards. When the resources are drained more than the potential rewards, the user will opt not to take the action. The application must, therefore, reduce the number of clicks to perform an action, reduce cumbersome authentications and payments, and reduce the number of choices presented to the respondent because the more the options, the more mental effort is required to compare, evaluate and decide. People often follow the path of least resistance.

- Have **triggers**, prompts, cues, and CTAs (call to actions- requiring each page to indicate the desired user response clearly) in the respondent's path to stimulate action even when motivation levels might be low. A developer-initiated prompt or reminder preferably in the form of push notifications can be especially effective when they are actionable, personalised, and timely. If the user engages with the prompt and fulfils the necessary action, they should be rewarded with a congratulations screen or a badge. Pitfalls to avoid would be push notifications at inopportune times or with irrelevant content, and repeated notifications even after the respondent dismisses it could easily backfire. According to the Prospect Theory, people are more likely to act when the pain of loss is more than the pleasure of an equivalent gain which implies that people are averse to loss and are prone to act to avoid missing out on something than to secure a guaranteed gain. The application messaging should, therefore, try to emphasise on what users might lose if they do not act, instead of what they gain if they do (Miles, 2017).

- Boost user **motivation** with persuasive messaging or engaging game elements. The application should provide extrinsic motivation such that the outcome (monetary reward) rather than the rewards of the behaviour itself is what drives action, for example offering existing users a monetary incentive for getting their friends to sign up to the application. Intrinsic motivation such that the users derive satisfaction from using and sharing the application, without needing an additional incentive is necessary. The application should provide a sense of adventure or mystery by having surprise rewards (unannounced) to keep users engaged. This could be as easy as having a spin the wheel feature that encourages respondents to spin every day for a chance of winning a surprise gift. This is a gambling-like reward where users chase a dopamine rush. All this is to trigger user engagement.

It is more advantageous to attract people using extrinsic rewards (monetary rewards, discounts and gift cards, coupons, giveaways, raffles and sweepstakes, freebies, charity donation, and so forth), then transition their interest through intrinsic rewards (status). These rewards can be given to every respondent, to the first respondent(s), or selection of respondents from a lottery. Prepaid incentives, those given during the survey, are more effective in increasing response rates than promised incentives but are more expensive because you reward everyone, including those who drop out of the survey after receiving the reward or before completion of the study. There is, however, a delicate balance that should be maintained because of the over-justification effect, which suggests that offering extrinsic rewards for something users were already sufficiently motivated to do would decrease their intrinsic motivation (Miles, 2017). Offering incentives might also harm the quality of feedback received. This application is intended to be a free application on the Google Play Store, available to all users in the target areas.

4.6. Walkability survey questions

The previous iteration of the application audited route level walkability using four factors on a scale of 0-5; Comfort, Safety, Infrastructure and Security. The 0-5 Likert scale was as follows;

0- No provision made
1- Very Low
2- Low
3- Moderate
4- High
5- Very High

Table 4-2: Walkability application survey questions

Comfort	Safety	Infrastructure	Security
1. Rate the cleanliness and maintenance of your walking environment	5. Rate the provision of safe crossings along your route e.g. zebra crossings/ pedestrian malls/signalized intersections**	9. Rate the quality of pavement material	11. How much pedestrian oriented lighting is available along your route**
2. Rate the degree of path drainage along your route	6. Rate your sense of safety from injury caused by motorised transport	10. Rate the provision of walking space along the route**	12. Rate the level of human activity along the streets that make up your route
3. Rate the degree of obstruction along the route	7. Give a rating for the amount of moving motorised transport along your walking route		13. Rate your sense of personal security while walking along your route
4. Rate the provision of pedestrian oriented amenities such as dustbins and public seating along the route**	8. Give a rating of how you perceive the speeds of motorised transport along your route		
Demographic and general questions			
What is the most important factor associated with choosing your route?	How often do you walk to public transport in this area?	Did you walk indoors	Do you have access to motorised transport for this trip?
Gender	Age		

(Adapted from Wasswa, 2016)

The questions above have redundancy and can further be simplified and reduced to prevent interview fatigue. The application reduces and simplifies the number of questions asked while still covering a broader set of factors. The questions would vary depending on the street and the amenities available on it as determined by the Open Streets Maps. In other words, the user will not be asked questions on the condition of a bus shelter on a street without bus shelters or where the user has already indicated that there are no bus shelters present. The questions would be divided into themes;

i. Transportation questions such as CO_2 footprint;
ii. Ordinary user preference questions such as the width of footpaths and comfort.

In addition to the above, the questions asked will be tailor-made for a particular location or country, based on the characteristics and circumstances of the area. In other words, the researchers or authorities conducting the walkability audit will have the ability to specify what elements to ask respondents on, or what to focus on because priorities may differ in different places. The same is possible on the surface overlay with questions at the top of the screen as an alternative input method which can also be edited to fit the intended purpose. This will also serve as a mechanism to facilitate a learning environment for the expert and the user to collaborate. The application has functionality allowing modification of these audit questions.

Table 4-3: User response -Application Interaction

Category	Sample triggered question	User Response
Infrastructure availability and condition (Includes Universal Access)	1. Is the width of the footpath wide enough for at least two adults to walk side by side? 2. Is the street ahead closed (for instance, for repairs)? 3. Is the footpath clean? Is it slippery? 4. Is the footpath Continuous and well designed? 5. Are the markings on the crossing ahead still visible? 6. Which of the following is either in poor condition or missing: Ramps, Benches, Signboard, Escalator, Bus shelter, Handrails, Tactile paving, et cetera? 7. Is the walkway present on both sides of the street? 8. Is the landscape attractive to you?	Yes/No and can give more details including photographs and recording a video.

Category	Sample triggered question	User Response
Safety and Security	1. Is the street light on your left still working? 2. Are motorists respectful of pedestrians (i.e. slowing down at crossings and not hooting)? 3. Are vehicles encroaching or parked on the footpath? 4. Are there obstructions in your path such as transformers, trees, et cetera? 5. Are there enough pedestrian crossings? 6. Would you walk this route with a/your child at night?	Yes/No. Based on the respondent's response, additional details will be sought such as how safe they feel at that precise moment
Comfort	1. Are you comfortable with the speed of vehicles around you? 2. Are the noise levels excessive? Are they excessive compared to other parts of the City? 3. Is the path well-drained and without puddles of water? 4. Is the path too steep for comfortable walking? 5. Are the bike lane and walking paths separate?	Yes/No. If the respondent answers No, an additional question will be asked to determine if the vehicles are too fast and an approximation of the speed in Km/h
Universal Access	Could someone make use of the sidewalk/paths using a wheelchair, walker, stroller, or other mobility aids without difficulty?	Yes/No and can give more details including photographs and recording a video.

The reliability of the data collected depends on the assumption that there is access to good and affordable smartphones and that people are not afraid to use them, including at night times. The analysis requires consistent data for comparable modelling, standardisation, filling of gaps, and accuracy.

5. DISCUSSION OF RESULTS

The aim of this research project leading to the results detailed in the previous section was to gain valuable knowledge on the emerging technological innovations in the context of walkability assessments in developing nations using mobile devices. In particular, the literature reviewed previous studies, models, and case studies which would hence provide potential sources of information for the development of this prototype mobile application.

From the review of sampled literature and the results presented above, it is evident that the age of Big Data and disruptive technologies is upon us and its potential to predict and manage the future of business, planning, and technology is inevitable. We are experiencing a vital shift in how technology integrates with, alters, and improves society and its functions. The chips and processors in our devices have become more powerful and cheaper, and there are now many varied sources of data that is more precise, allowing the extraction of useful information and analysis of trends. Recognising the next disruption is not enough; instead, one needs to act upon it before they are left behind when other innovators take it up.

Walking is favoured as a popular means of mobility because it is cheap, more sustainable, and universally available. Previous studies have categorically reported that low levels of walking among the population contribute to a myriad of health problems and promote the growth of less sustainable use of private motor vehicles which contribute to pollution and increased CO_2 emissions. Transport-based mobile phone applications currently available in the market are increasingly getting outdated and not keeping up with new and emerging technologies and innovations.

It is now evident that if there is to be a revolution or disruption in the use of mobile phone technology in the collection of user perceptions of walkability, it is likely going to come with the advent of advanced analytics, Augmented Reality, and Artificial Intelligence in the device. While studying the available literature, some questions remained unanswered, namely; what are the emerging technological innovations that can be applied in improving the current application, how practical they are in terms of cost, device specifications, and computing power, and what the framework for such an application is. There was not enough information to extract any comprehensive and meaningful patterns from the literature review alone, hence the need to do this research project to attempt to fill those information gaps.

Having discussed: the need to promote and assess walkability; limitations of available transport-based apps and their use; emerging technologies in this space; and the technical and functional requirements for devices; this research has shown the applicability of mobile phone technology in aiding transport research. It has also shown that the latest mobile smartphone technologies as contrasted with the status quo, can further disrupt and revolutionise the collection of transport-related information in innovative and intuitive ways, presenting the case for more initiatives to take advantage of this emerging opportunity. A conceivable economic use case for this data collection tool is for developers, local and national government, businesses, lenders and investors to customise their activities, interventions, and funds based on their urban design profiles. The various walkability parameters in the application, count differently in their financial models. In other words, it can be used as an economic development tool facilitating their identification of activities or modifications that would produce the most positive social and environmental impact. This economic case viability must be based on actual real data and not just novel ideas such as social good for the community and public spaces. This tool can also be useful for assessing real estate alternatives; home-buying or renting based on walkability.

6. CONCLUSION

All things considered, with all the challenges in developing countries, it is vital to be aware that dashboards, sensors and applications cannot solve congestion, poverty, inequality, poor sanitation and crumbling infrastructure. The problems in these cities require policies and research, but authorities are not paying enough attention to this. A combination of policy measures will have to drive that change, as there are limits to what technology on its own can do. As has been noted, pedestrians are still mostly invisible in traffic management systems, and despite the increased attention to them, it is still not to the same level as vehicular traffic. In the design process, sustainable modes should be prioritised over less sustainable modes, and dedicated space should be allocated to pedestrians and cyclists.

Walkability promoting infrastructure and facilities must be provided to create some form of journey ambience for pedestrians that will encourage them to walk more to their destinations. It is therefore essential to have technology that is better and quicker in measuring and collecting transport data to inform these policies, plans and infrastructure programs. Presently available tools in the market do not factor the complete range of problems facing pedestrians, particularly in developing countries. New tools taking cognisance of this fact will be necessary, and smartphone applications like the one developed in this research could provide the much-needed solution.

This research project has demonstrated a system prototype in an operational environment, in a way which is not only unique for Africa but has not been done before. This meets the all-encompassing aims and objectives of this research. The results chapter unpacked the technical and functional requirements for the collection of walkability-related data. The Walkability mobile application was created to harness the power of crowdsourcing and the potential created by the massive growth in mobile technology. This pilot application proved the concept of how location-based triggers, Augmented Reality (AR), Big Data, and Machine Learning (ML) can be leveraged to minimise data entry for journeys already surveyed. The tool provided a shift away from the mechanistic approach to understanding pedestrian challenges and facilitated the prioritisation of walking as a more sustainable and equitable means of mobility.

The application inhibits strengths and advantages over traditional methods of transport data collection such as travel diaries and surveys which are characterised by the under-reporting of trips and other information. By combining artificial and human intelligence, the application presents a new way of collecting this information that is more effective and has the potential to be a disruptive innovation. Big Data coupled with predictive analytics and Machine Learning, is an effective combination for effective planning maintenance and managing transport networks.

Additionally, since all reports received are geo-referenced, they can be aggregated and analysed using various GIS and mapping tools to detect trends and draw useful inferences. An Android Operating System application was preferred due to its more significant market share in the developing countries compared to Apple iOS and other operating systems. In essence, during the application testing and pilot phase, feedback from users was incorporated to address potential shortcomings and sort out bugs in the application.

By and large, user buy-in into an application is required particularly in the initial stages of a crowdsourcing application until the user base of the crowdsourcing platform has reached sufficient size referred to as a 'critical mass' for autonomous operation. The adoption rate of the application will naturally increase with improved smartphone penetration and internet data coverage, coupled with decreasing handset prices. While this presents opportunities for emerging ICT solutions that involve crowdsourcing, it also requires resources and endurance to sustain the application until the user base has reached a critical mass. The application can thus be used for enhanced citizen engagement through dynamic mobility surveys using smartphones. The crowdsourced data collected can be regarded as having value as it represents an alternative source for official statistics which is large enough (and otherwise of sufficient quality) to improve official statistics. The transformation of official statistics has already started, with many official statistics producers and international statistical bodies, entering the Big Data market in recent years. The information gathered would contribute to good governance by informing policy actions that could help to promote good health and well-being whilst promoting sustainable cities and communities.

The key to success is to engage with Big Data as one would any other data, and to give it due recognition as part of making data meaningful (Florescu et al., 2014). The overarching aim of leveraging Big Data should not be to amass an enormous amount of data but to turn the data into useful information, and the information into valuable insight. Mobile smartphones have revolutionised the collection of transport-related information hence the need for new initiatives to help take advantage of this emerging opportunity. There is still tremendous potential that Big Data can supply to transportation. This is likely to increase as more advanced technologies, such as automation and Artificial Intelligence, are embedded into networks.

Based on the conclusions drawn above, the constant review of literature, and the questions that emerged in the course of this research, I am convinced that much more research, particularly on what technologies and functionalities can realistically be incorporated into mobile phone applications in the near future, should be done. It is also recommended that other operating systems, apart from the Android system, be considered when creating such tools to reach a broader base of users. Further research should also be conducted on improving the hardware specifications of mobile phone devices to facilitate and support these emerging technologies while keeping the cost of mobile devices as low as possible.

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APPENDIX

Appendix A: Ethics Approval

APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form before collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/ebe/research/ethics1

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		WILBERFORCE WANJAU CHEGE
Department		EBE
Preferred email address of applicant:		CHGWIL003@MYUCT.AC.ZA
If Student	Your Degree: e.g., MSc, PhD, etc.	MENG TRANSPORT STUDIES
	Credit Value of Research: e.g., 60/120/180/360 etc.	60
	Name of Supervisor (if supervised):	A/PROF. MARK ZUIDGEEST
If this is a researchcontract, indicate the source of funding/sponsorship		
Project Title		Development and testing of a mobile phone-based data collection tool that incorporates augmented reality and machine learning in collecting data on walkability

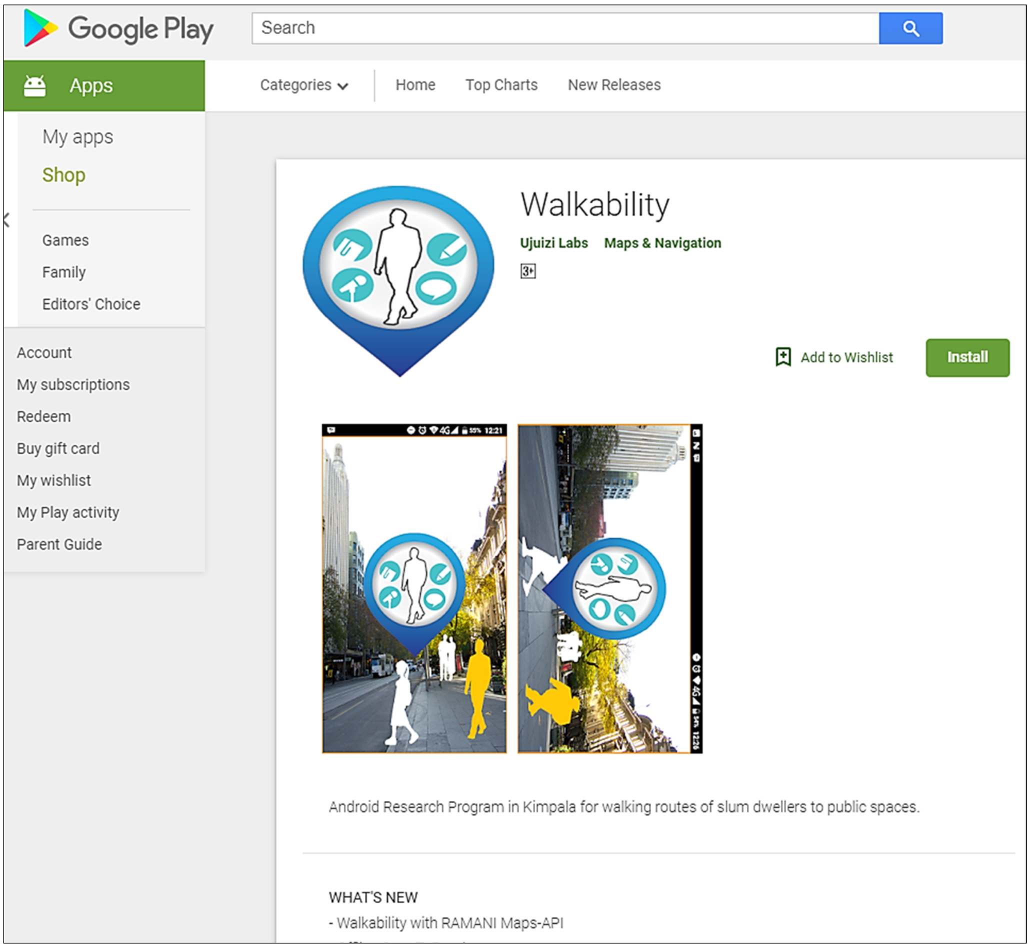
I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

SIGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	WILBERFORCE CHEGE	Signature Removed	31 Jul 2018

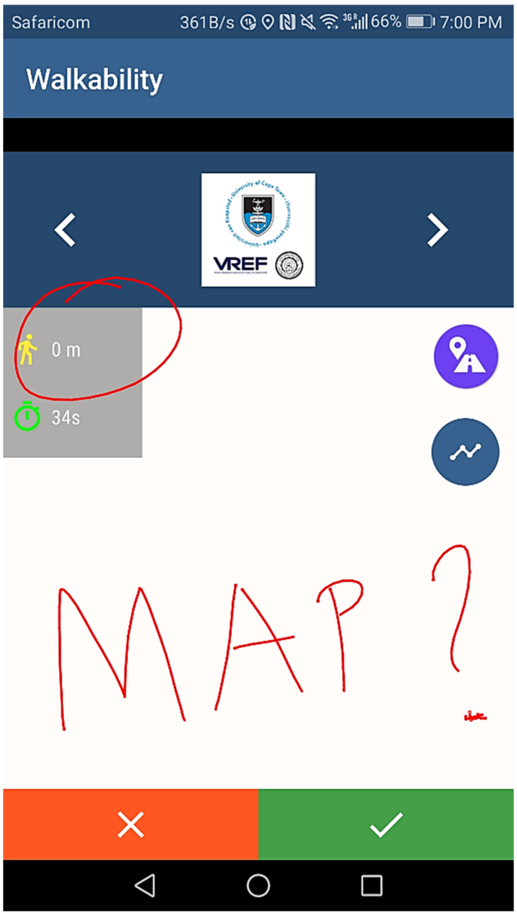
APPLICATION APPROVED BY	Full name	Signature	Date
Supervisor (where applicable)	A/PROF. MARK ZUIDGEEST	Signature Removed	01 Aug 2018
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section1; and for all Undergraduateresearch (including Honours).	Click here to enter text. Dyllon Randall	Signature Removed	Click here to enter a date. 06.08.2018
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above			

Appendix B: Application Registration on Google Play Store

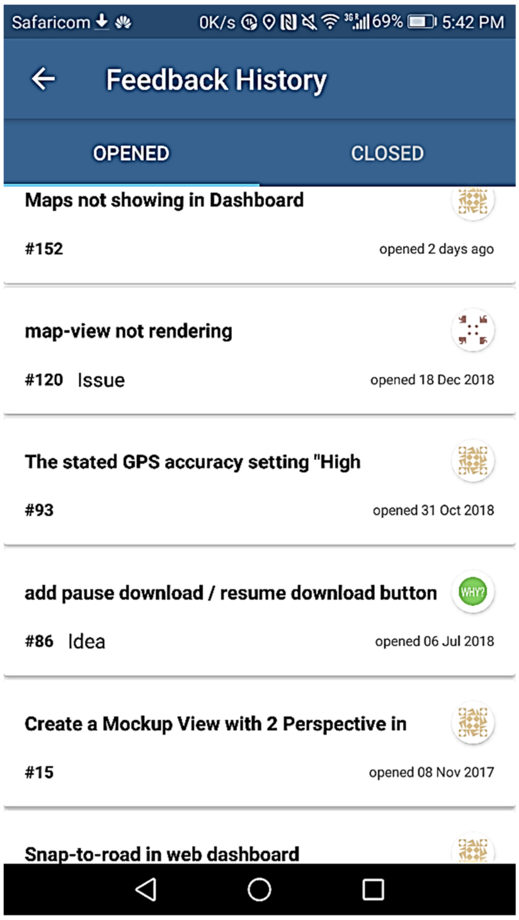


Walkability application available on the Google Play Store

Appendix C: Application Screen Dumps



Annotated Feedback Screen

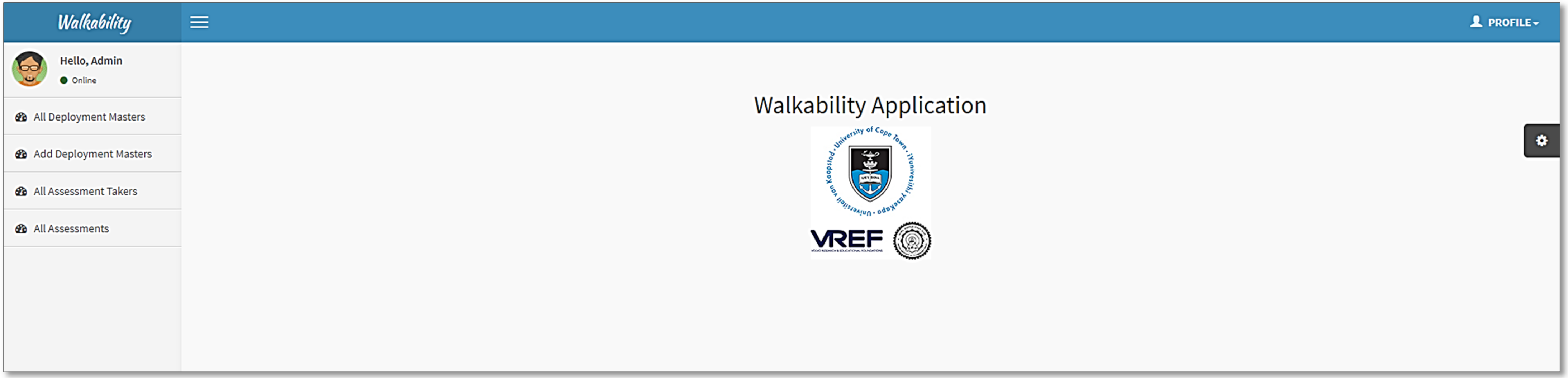


Feedback History (Oen/Closed issues)

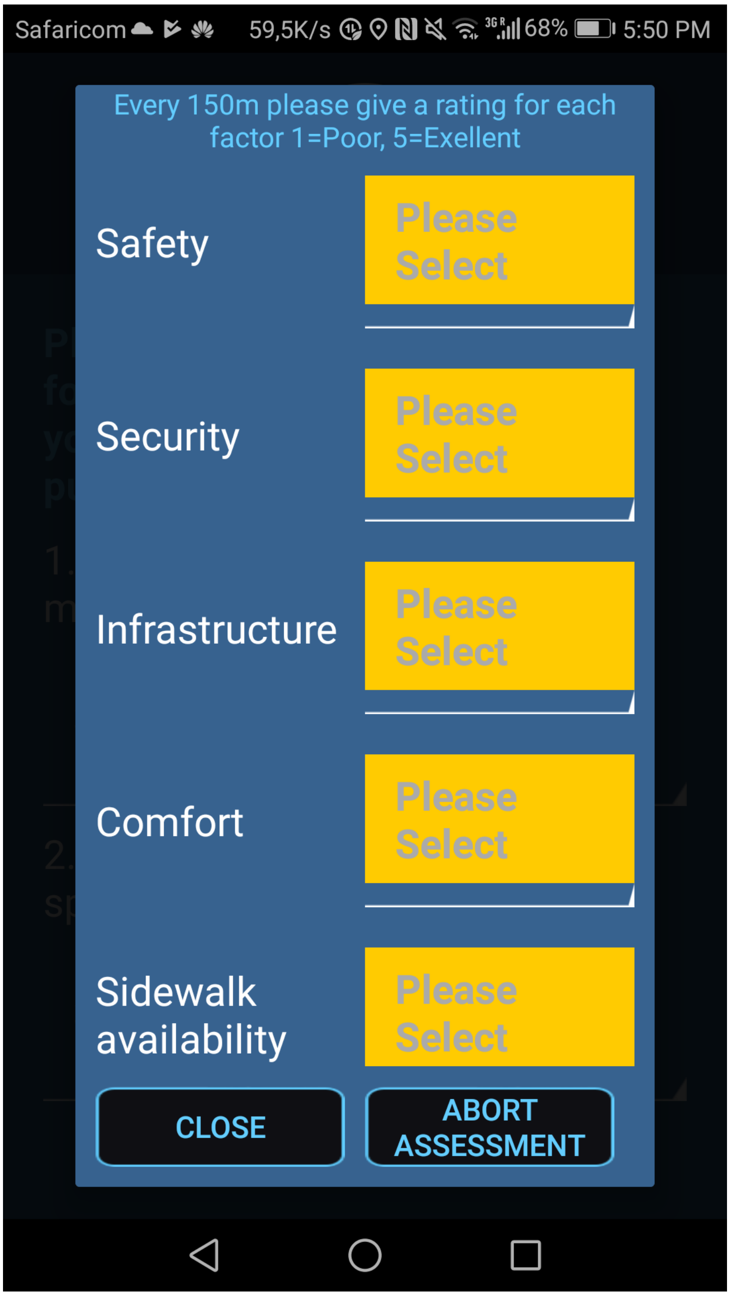
Start Time	End Time	View route	Export	Export	Delete
2019-01-04 08:03:47	2019-01-04 08:05:05	View Full Assessment	Qualitative ▾	Export	Delete
2019-01-03 20:51:32	2019-01-03 20:56:23	View Full Assessment	Segment ▾	Export	Delete
2019-01-03 20:43:56	2019-01-03 20:51:27	View Full Assessment	Route ▾	Export	Delete
2019-01-02 06:03:33	2019-01-04 06:46:26	View Full Assessment	Text ▾	Export	Delete
2018-12-31 00:13:06	2018-12-31 00:24:09	View Full Assessment	Image CSV ▾	Export	Delete
2018-12-29 05:26:59	2018-12-29 05:36:05	View Full Assessment	ALL Image ▾	Export	Delete
2018-12-28 12:02:39	2018-12-29 02:12:39	View Full Assessment	Audio CSV ▾	Export	Delete
2018-12-27 23:03:48	2018-12-27 23:07:38	View Full Assessment	All Audio ▾	Export	Delete
2018-12-27 22:53:37	2018-12-27 22:57:57	View Full Assessment	Qualitative ▾	Export	Delete
2018-12-27 20:49:37	2018-12-27 20:52:02	View Full Assessment	Qualitative ▾	Export	Delete
Start Time	**Last Time**	**View route**	**Export**	**Export**	**Delete**

1 2 3 4 5 Next ⟶

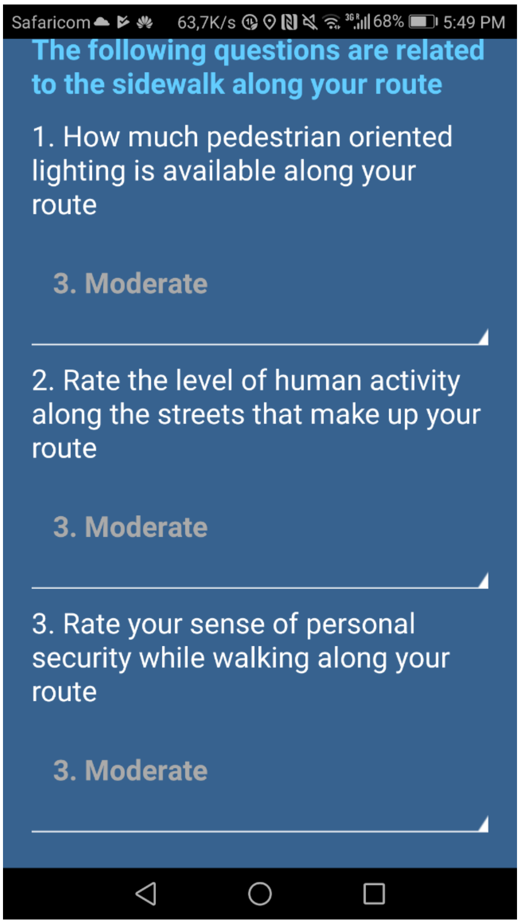
Downloadable data from the web dashboard

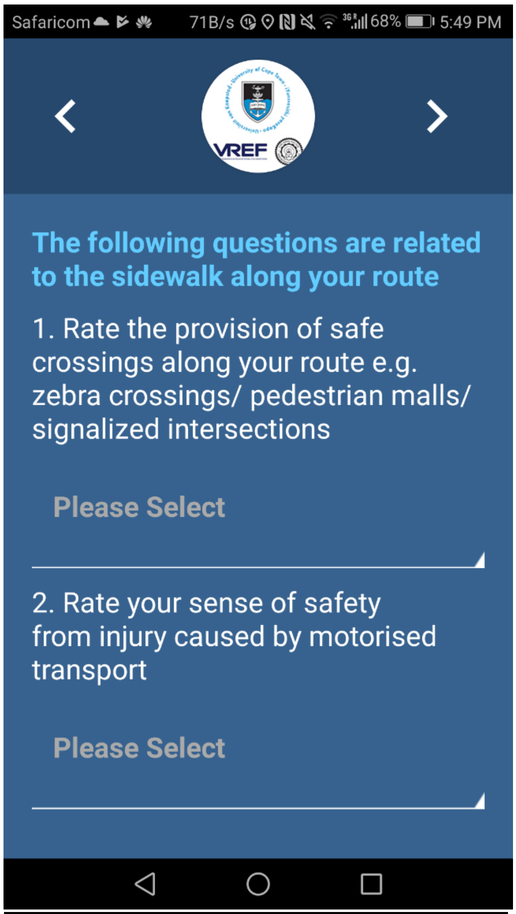


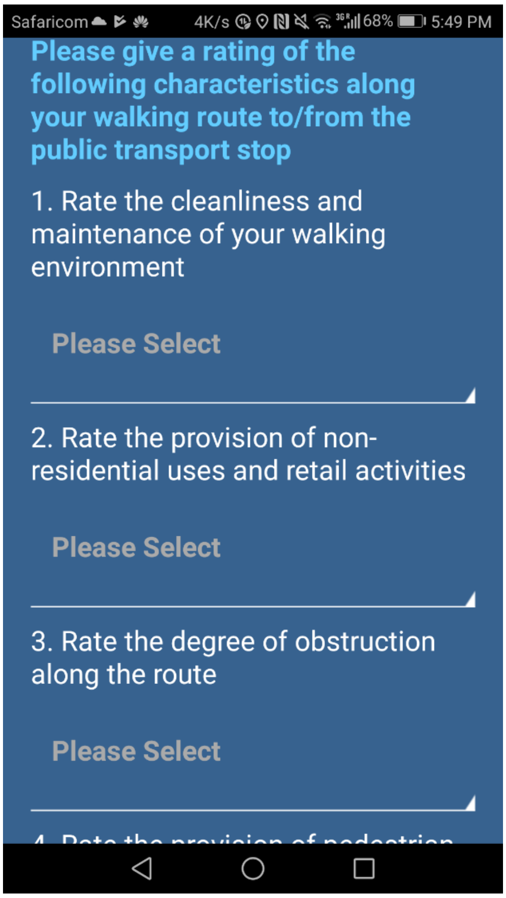
Dashboard welcome and log-In screen

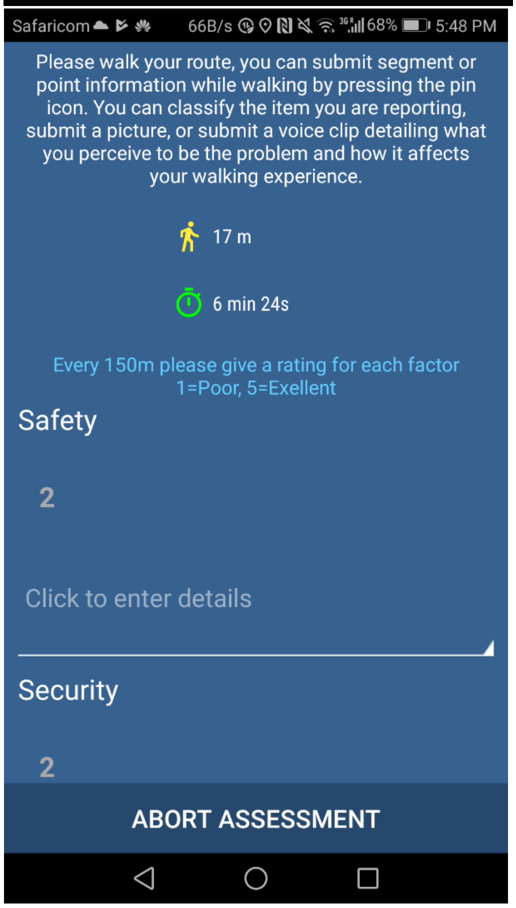


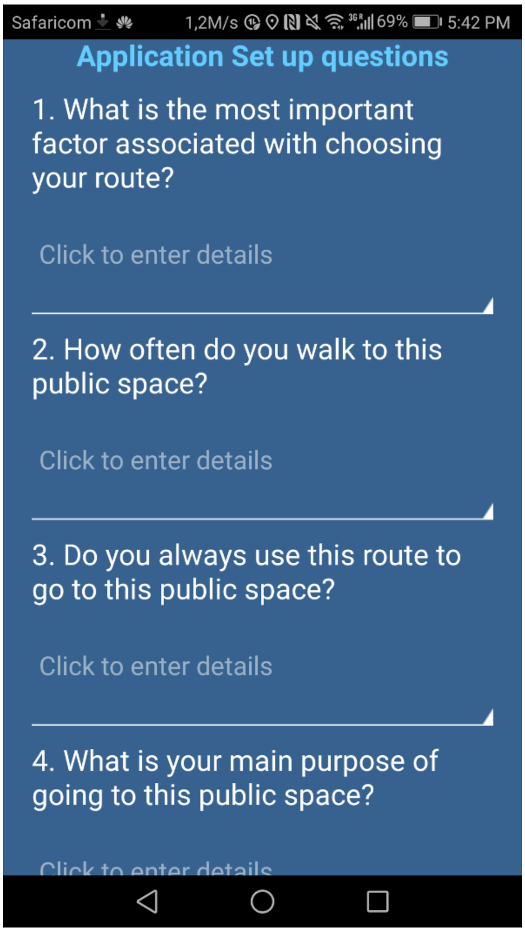
Feedback request after every 150m

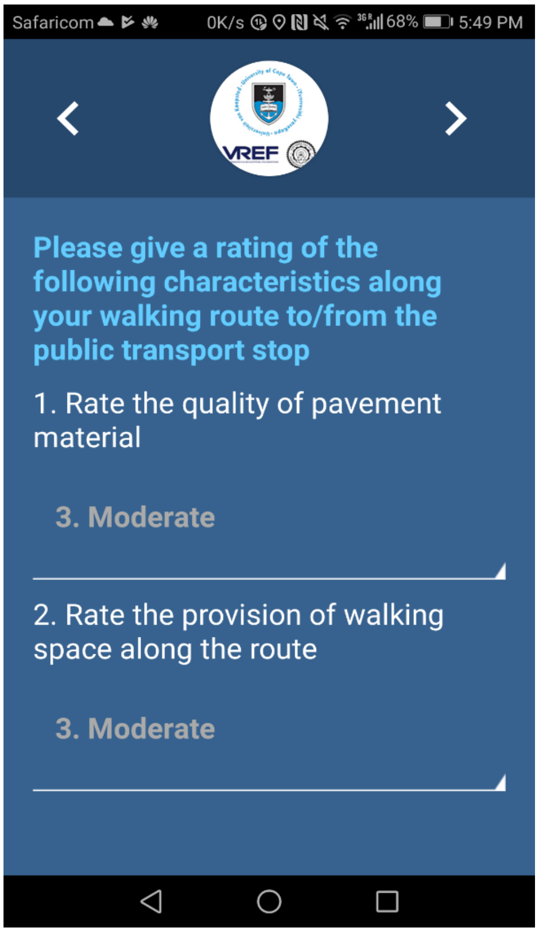

Safaricom 63,7K/s 68% 5:49 PM
The following questions are related to the sidewalk along your route
1. How much pedestrian oriented lighting is available along your route
3. Moderate
2. Rate the level of human activity along the streets that make up your route
3. Moderate
3. Rate your sense of personal security while walking along your route
3. Moderate

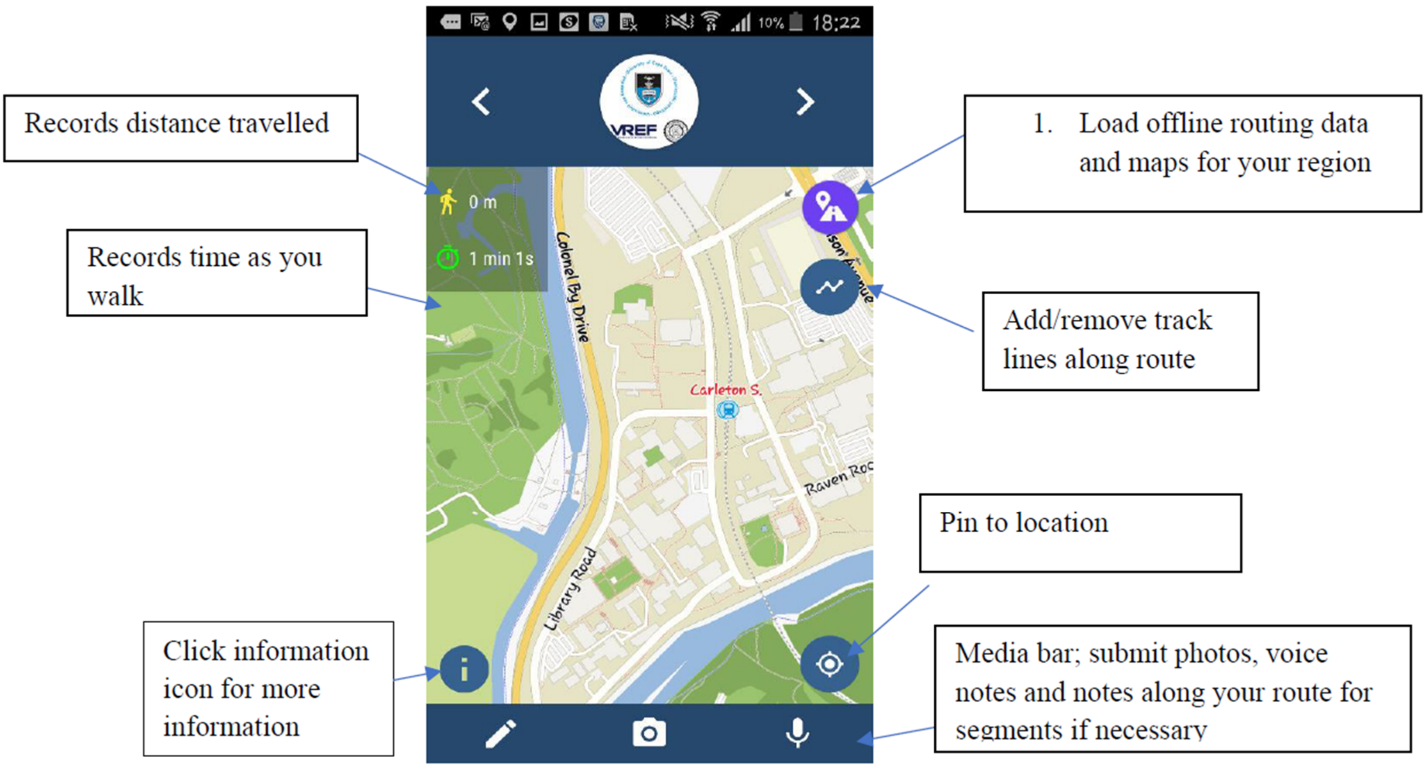

Safaricom 71B/s 68% 5:49 PM
VREF
The following questions are related to the sidewalk along your route
1. Rate the provision of safe crossings along your route e.g. zebra crossings/ pedestrian malls/ signalized intersections
Please Select
2. Rate your sense of safety from injury caused by motorised transport
Please Select


Safaricom 4K/s 68% 5:49 PM
Please give a rating of the following characteristics along your walking route to/from the public transport stop
1. Rate the cleanliness and maintenance of your walking environment
Please Select
2. Rate the provision of non-residential uses and retail activities
Please Select
3. Rate the degree of obstruction along the route
Please Select


Safaricom 66B/s 68% 5:48 PM
Please walk your route, you can submit segment or point information while walking by pressing the pin icon. You can classify the item you are reporting, submit a picture, or submit a voice clip detailing what you perceive to be the problem and how it affects your walking experience.
17 m
6 min 24s
Every 150m please give a rating for each factor 1=Poor, 5=Exellent
Safety
2
Click to enter details
Security
2
ABORT ASSESSMENT


Safaricom
1,2M/s 69% 5:42 PM
Application Set up questions
1. What is the most important factor associated with choosing your route?
Click to enter details
2. How often do you walk to this public space?
Click to enter details
3. Do you always use this route to go to this public space?
Click to enter details
4. What is your main purpose of going to this public space?


Safaricom
0K/s 68% 5:49 PM
VREF
Please give a rating of the following characteristics along your walking route to/from the public transport stop
1. Rate the quality of pavement material
3. Moderate
2. Rate the provision of walking space along the route
3. Moderate


Records distance travelled
Records time as you walk
Click information icon for more information
1. Load offline routing data and maps for your region
Add/remove track lines along route
Pin to location
Media bar; submit photos, voice notes and notes along your route for segments if necessary
10% 18:22
VREF
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Carleton S.
Raven Ro
Library Road

Appendix D: Turnitin Report

turnitin

Digital Receipt

This receipt acknowledges that Turnitin received your paper. Below you will find the receipt information regarding your submission.

The first page of your submissions is displayed below.

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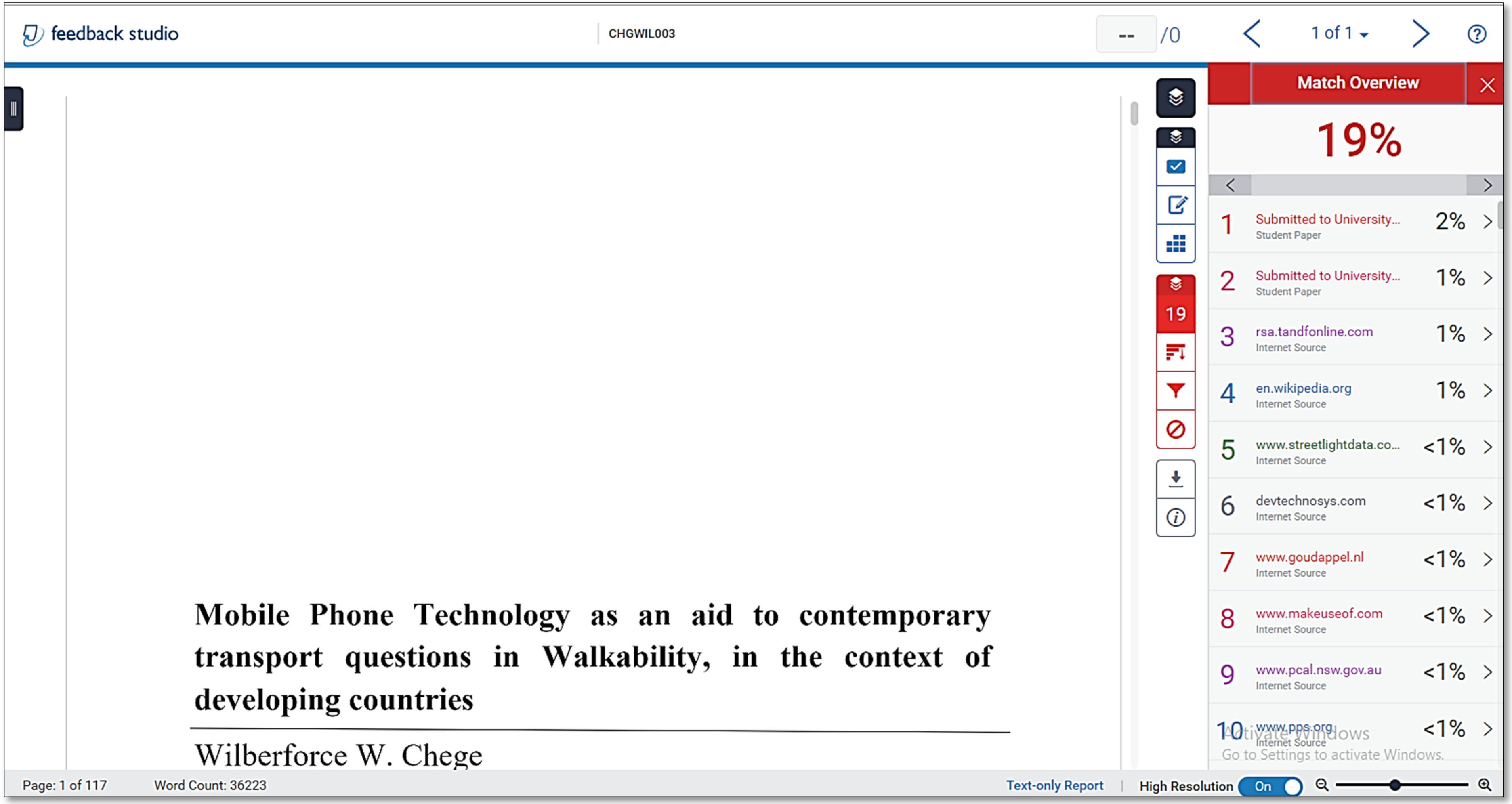
Assignment title:	Masters Thesis
Submission title:	CHGWIL003
File name:	MEng_Research_Thesis-Wilberfor...
File size:	15.81M
Page count:	117
Word count:	36,223
Character count:	217,385
Submission date:	31-Jan-2019 06:42PM (UTC+0200)
Submission ID:	1071106980

Mobile Phone Technology as an aid to contemporary transport questions in Walkability, in the context of developing countries

Wilberforce W. Chege

UNIVERSITY OF CAPE TOWN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1 of 1
Match Overview
19%
1 Submitted to University... Student Paper 2%
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4 en.wikipedia.org Internet Source 1%
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19
Mobile Phone Technology as an aid to contemporary transport questions in Walkability, in the context of developing countries
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Page: 1 of 117
Word Count: 36223
Text-only Report
High Resolution On
Activate Windows
Go to Settings to activate Windows.