Pre-Feasibility Model for the Creation of Green Pedestrian Zones

by
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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: April 2019

ABSTRACT

City centres facilitate various activities ranging from business and cultural activities to providing residential accommodation (Coca-Stefaniak, 2013). A healthy environment is of importance to ensure the optimal functioning of a city or town centre for its users and residents (Derby City Council, 2017). Unfortunately it can be expected that future environmental problems may be concentrated in urban areas (CSIR, 1999).

There are various methods to aid in mitigating the negative effects associated with environmental problems (Hawley, 2014). In this study, green pedestrian schemes are investigated as a solution.

By creating pedestrian zones in city areas, also utilizing green engineering technologies, the amount of green space in the city per capita will increase (Lee *et al.*, 2015). It is anticipated that with more green space, there should be retardation in urban sprawling and other associated benefits including environmental, health, social and economic benefits (Blaga, 2013).

The primary aim of this study is to develop a pre-feasibility model to be used as aid in determining if the implementation of a green pedestrian zone would be feasible in an area as identified by local authorities. The pre-feasibility model entails a combination of mathematical modelling and other decision modelling techniques. The pre-feasibility model consists of two parts namely a location characteristic checklist and a mathematical model.

The location characteristic checklist aids in determining whether a proposed area would be suitable for a successful pedestrian zone. From literature and industry critique it can be concluded that the most significant characteristics for a successful pedestrian zone are that the area should have a mixed land use, should be within close proximity of public transport facilities and should provide a sense of safety and security.

The second part of the pre-feasibility model is a mathematical model. The effects of pedestrian schemes on air quality, economic factors, social factors and the traffic on the surrounding network are modelled. Multiple linear regression was used to predict what the expected increase or decrease in certain air pollutants could be post pedestrianization as a result of the removal of vehicles and the application of green engineering technologies to the proposed area. Averages of previous studies regarding economic, social and traffic circumstances are determined and are presented in the pre-feasibility model as anticipated and expected benefits.

As a final step, the developed pre-feasibility model is applied to the inner town centre of Stellenbosch. From the model outputs it is concluded that the identified area of Church Street, Andringa Street and Ryneveld Street adhere to most of the location characteristics except for the proposed area not being within close proximity of public transport facilities. It is further found that the pedestrian scheme may have a slight worsening effect on the air quality in total. The implementation of green engineering technologies will however contribute to the removal of additional air pollutants. The predetermined economic and social benefits are expected to be positive based on previous studies.

OPSOMMING

Verskeie aktiwiteite word deur ‘n middestad geakkomodeer. Hierdie aktiwiteite sluit besigheids- en kulturele aktiwitieite in asook verblyfsgeleenthede (Coca-Stefaniak, 2013). Die welstand van ’n middestad speel dus ‘n belangrike rol om te verseker dat die stad optimaal funksioneer (Derby City Council, 2017). As gevolg van vinnige verstedeliking en groei in die bevolkingsdigtheid, word daar verwag dat toekomstige omgewingsprobleme in stedelike areas gekonsentreerd sal wees (CSIR, 1999).

Daar is verskeie metodes om die negatiewe uitwerking van hierdie omgewingsprobleme teen te werk (Hawley, 2014). Groen voetgangersones word in hierdie studie nagevors as oplossing.

Deur voetganersones met addisionele groen ingenieurstegnologieë in stedelike gebiede te skep, is daar ‘n toename in die groen spasie area per persoon (Lee *et al.*, 2015). Daar word verwag dat meer groen spasie ‘n vertraging in stedelike verspreiding asook ander voordele soos omgewing-, gesondheids-, sosiale- en ekonomies voordele teweeg sal bring (Blaga, 2013).

Die hoofdoel van hierdie studie is om ‘n pre-lewensvatbaarheid model te ontwikkel wat gebruik kan word as hulpmiddel om te bepaal of die implementering van ‘n groen voetgangersone in ‘n area, soos geidentifiseer deur plaaslike owerhede, lewensvatbaar sal wees of nie. Die pre-lewensvatbaarheid model is ‘n kombinasie van ‘n wiskundige model en ander besluitnemingstegnieke. Die pre-lewensvatbaarheid model bestaan uit twee dele, naamlik ‘n kontrolelys en ‘n wiskundige model.

Die kontrolelys vir ligging eienskappe help in die bepaling of ‘n voorgestelde area vir ‘n voetgangersone gepas sal wees om ‘n suksesvolle voetgagersone te verseker. Vanuit die literatuur en kritiek ontvang vanuit die industrie, is daar tot die gevolgtrekking gekom dat noodsaaklike eienskappe vir ‘n suksesvolle voetgangersone insluit dat die area gemengde gebruike moet hê, dat die area naby publieke vervoer fasiliteite moet wees en dat die area die gevoel van veiligheid en sekuriteit moet skep.

Die tweede gedeelte van die pre-lewensvatbaarheid model is ‘n wiskundige model. Die uitwerking van voetgangersones op die kwaliteit van die lug, ekonomie, sosiale aspekte en die verkeer in die omliggende netwerk word gemodelleer. Veelvoudige lineêre regressie is gebruik om te voorspel wat die verwagte toename of afname in sekere lugbesoedelingstowwe sal wees na die implementering van ‘n voetgangersone as gevolg van die verwydering van voertuie en die toepassing van groen ingenieurstegnologieë in die voorgestelde area. Die gemiddeldes van vorige studies in verband met die ekonomiese-, sosiale- en verkeerstoestande is bepaal en voorgestel in die pre-lewensvatbaarheid model as verwagte voordele.

Die pre-lewensvatbaarheidmodel is toegepas op die middedorp van Stellenbosch. Vanuit die modelresultate kan afgelei word dat die voorgestelde area van Kerkstraat, Andringastraat en Ryneveldstraat voldoen aan die meerderheid liggingeienskappe behalwe dat die voorgestelde area nie naby publieke vervoer fasiliteite geleë is nie. Verder is daar gevind dat die voorgestelde voetgangersone ‘n effense negatiewe uitwerking op die kwaliteit van lug sal hê. Die implementering van groen ingenieurstegnologieë sal egter bydra tot die verwydering van addisionele lugbesoedelingstowwe. Betreffende die ekonomiese en sosiale voordele word daar verwag dat dit positief sal wees soos bepaal uit vorige studies.

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LIST OF ABBREVIATIONS

CBD:	Central Business District
CO:	Carbon Monoxides
CO_2:	Carbon Dioxide
EPI:	Environmental Performance Index
GDP:	Gross Domestic Product
GIS:	Geographical Information System
GPZ:	Green Pedestrian Zone
HC:	Hydrocarbons
IDP:	Integrated Development Plan
LEZ:	Low Emission Zone
LOS:	Level of Service
NATIS:	National Administration Traffic Information System
NO_2:	Nitrogen Dioxide
NO_x:	Nitrogen Oxides
O_3:	Ozone
PM:	Particulate Matter
ppm:	Parts Per Million
SO_2:	Sulphur Dioxide
UFORE:	Urban Forest Effects Model
WHO:	World Health Organization

1. INTRODUCTION

City and town centres sustain the local community, provide a retail platform, are environments for leisure and entertainment and provide a means for people of different cultures to express themselves. City centres serve as a connection between the private and public sectors, are synonymous with employment and serve as the Central Business District (CBD). The state of any city or town centre is therefore of significant importance (Coca-Stefaniak, 2013).

More than half of the world's population is living in cities and South Africa is no exception. According to the July 2018 estimates of the United Nations, the current population of South Africa is 57.4 million of which 62.9% is urban (Worldometers, 2018).

The consequence of an ever increasing urban population is that cities are one of the primary generators of greenhouse gasses (CIFF, 2017). Future environmental problems will be concentrated in cities and urban areas (CSIR, 1999). It is suggested that a possible solution to some of the environmental problems in city centres is the creation of green pedestrian zones (GPZs) in overpopulated and congested CBD areas. Green pedestrian zones can improve living conditions in city centres and will reduce the negative impact on everyday life of environmental problems, overpopulation and congestion (Soni & Soni, 2016).

In this thesis the feasibility of GPZs as a possible solution to environmental problems is researched. A mathematical model is developed as aid in determining the feasibility of GPZs in the CBD or town centre. The model will form an integral part of the decision making process of local authorities on the implementation of GPZs. The output of the model will assist in the decision making process as to proceed with the investment of a costly and detailed transport model and impact assessment or not.

The pre-feasibility model will provide a guideline on the preferred location to implement GPZs and will provide typical boundary conditions to incorporate. It will provide an approximation on the expected effects of implementing GPZs. The model will be derived from information and data obtained from the literature and findings from previous studies.

The effects of a typical green pedestrian zone on the town centre of Stellenbosch are researched as practical case study in applying the pre-feasibility model.

1.1 Problem Statement

A healthy environment is required for the optimal functioning of a city or town centre and its residents (Derby City Council, 2017). The vitality and viability of town centres should continually be assessed if meeting the development needs of the town and habitants.

Different areas in a town centre are associated with different roles and activities. Typical activities that are impacted by the state of the town centre include residential living, retail, business and leisure activities. An understanding of the development opportunities and character of the town associated with these activities can contribute to the successful and sustainable nature of any town centre.

The provision of public transport and provision for cycling and pedestrian zones are factors to be incorporated in the development plans of towns. Such town plans should underpin the town centre's economic, cultural and social roles (Derby City Council, 2017).

To restore a city's living environment to a healthy state, strategies to save energy, to reduce wastage, air pollution and consumption should be developed. Modern innovations to address these challenges should be introduced to existing and new developments not yet implemented (Riffat *et al.*,2016). Implementations such as pedestrian zones in New York, and superblocks in Barcelona are examples where innovative thinking restored the "souls" of these cities. In Copenhagen, where once there were cars, bicycles now dominate and the provision for the extensive use of bicycles has been made (Robinson, 2016), as seen in Figure 1.

Figure 1: Bicycle accommodation in Copenhagen, Denmark (Robinson, 2016)

South Africa, like many countries in the world, has environmental issues that can impede the growth of the country and quality of life. Many of the environmental issues in the country are due to overpopulation, urban sprawling and urbanization (Conserve Energy Future, 2017). In developing countries, like South Africa, adequate measures should be implemented to ensure that the country can achieve its development goals without harming the environment and preserving its quality of life for future generations.

High density city centres are perceived to cause many environmental problems faced worldwide and in South Africa. GPZs are proposed as a possible solution to improve the health of city centres and to address some of the causes of environmental problems such as air pollution and emission of greenhouse gases.

1.2 Aim and Objectives

The following primary research question is aimed to be addressed in this study:

1. Will the implementation of a green pedestrian zone be feasible in an area as identified by local authorities? As aid to answer this question, a mathematical pre-feasible model is postulated.

The objectives of the thesis are to:

1. Research the environmental problems faced today in city and town centres and methods to mitigate these problems;

2. Research previous studies of pedestrian zones and investigate how GPZs may improve environmental conditions, quality of life and whether GPZs are a feasible solution to mitigate some of the negative environmental impacts currently faced in city and town centres ;

3. Evaluate the best existing green engineering methods to include in green pedestrian zones typical applicable to South Africa;

4. Develop a model to determine the feasibility of a green pedestrian zone. The model will include describing factors on where to locate a green pedestrian zone, what the aspects are to consider when a proposed green pedestrian zone will be implemented and what positive effects can be expected once a green pedestrian zone is implemented. Though the aim would be to develop the pre-feasibility model as a mathematical model, the end result may include or be expanded with alternative decision modelling techniques.

   As case study and validation of the model, apply the mathematical model practically on the town centre of Stellenbosch.

1.3 Thesis Layout and Primary Focus of Thesis

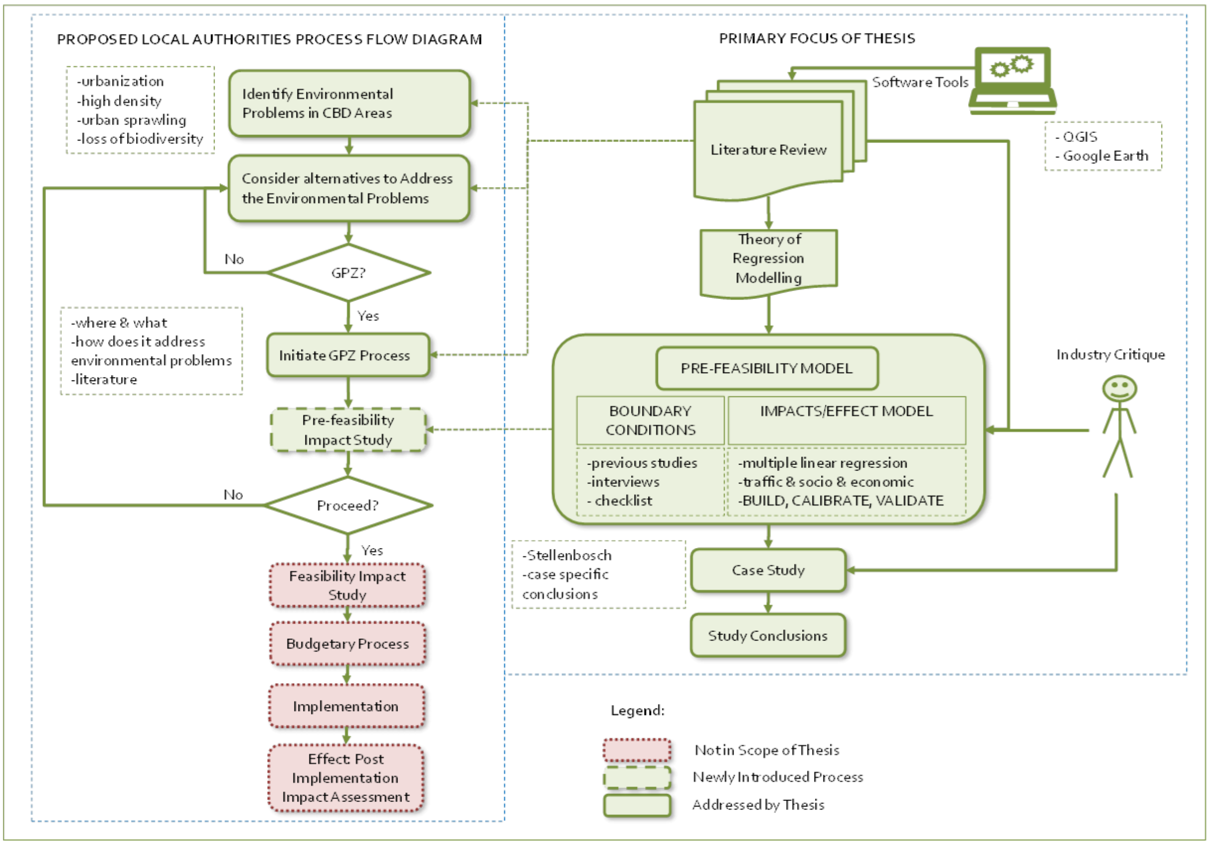

Figure 2: Scope of thesis

The proposed process flow that local authorities could follow leading up to the implementation of GPZs is illustrated on the left side of Figure 2. There is an overlap in the content of this process flow and the scope of the thesis. Processes indicated in green are addressed in the thesis while processes indicated in red are out of scope. The *Pre-feasibility Impact Study* process in the local authorities' process flow is of special interest as it utilises the pre-feasibility model as postulated within the scope of the thesis. Also within the scope of the thesis is the application of the pre-feasibility model in a case study.

From the thesis perspective, the processes in the flow diagram that local authorities could follow leading up to the implementation of GPZs are approached from an academic point of view through a literature study. From a local authorities' perspective, these processes will be abbreviated and more practical of nature.

1.4 Scope and Limitations

In this thesis only the *factors directly affecting* the quality of life of residents, retailers and pedestrians within the designated area and the road users on the network under consideration are addressed. These factors can be grouped into four main groups namely environmental factors, social and health factors (effects on people), economic factors and the traffic conditions. The scope of the thesis includes the following:

1. Environmental issues considered are those classified as high-priority and include aspects affecting air quality, water and sanitation, forests, biodiversity and habitat and the climate. The only environmental problems with a direct and immediate impact on the users of a potential pedestrian zone are air pollution and noise pollution. Therefore only air and noise pollution are included in the proposed pre-feasibility model.

2. Only aspects with an impact on the environment, social factors, economic factors and traffic conditions are included in the model as follows:

    - Environmental impacts such as the immediate reduction in significant air pollution materials;
    - Mental and physical health of the users of the area under consideration and how the quality of life within the area under consideration is perceived;
    - Impact of pedestrianized areas on surrounding traffic;
    - Direct economic impacts on restaurateurs and retailers within a typical study area;
    - Other aspects to consider when creating a pedestrian zone. These aspects include the design and layout considerations influencing the functioning of a proposed pedestrian zone, financing opportunities for the proposed pedestrian zone and planning considerations.

3. Results are mainly expressed in terms of percentage increase or percentage decrease. Cost related results are in terms of the South African Rand. Occasionally, different units are used and defined where applicable.

4. The data derived from previous studies are used as input in creating a mathematical model.

The pre-feasibility model includes only the process up to where an answer can be derived on whether the pedestrian zone in the identified area will be feasible or not. If the answer is positive, local authorities can then decide to continue with a more formal and in depth study as illustrated in Figure 2. The formal in depth study is however not in the scope of the thesis.

Other factors not included in the thesis, but which form part of the limitations are listed as follows:

1. Even though green technologies such as green roofs have the benefit of reduced run-off and storm water, run-off and storm water do not have an immediate impact on the users of a pedestrian zone and are therefore not included;
2. The numerical results presented as outcome of the model are based on data obtained from previous studies and industry knowledge. Limited industry data is available and therefore the data used in the mathematical modelling process places a limitation on the accuracy of the model outcome;
3. The purpose of the pre-feasibility is to aid in the decision making process and not to serve as a detailed transport model. With formal transport modelling being an expensive process, as confirmed by a transportation planner, Me Gerber in an interview, the pre-feasibility only serves as a first step to determine whether the second step of formal transport modelling will be worth the expense;
4. The only green engineering technologies considered are the implementation of green roofs and green walls within the designated area. These are relatively easy to install, maintain and are readily available in South Africa. Other green engineering technologies such as green pavements and renewable energy methods (i.e. solar panel bicycle lanes) are not considered.
5. The scope of city and town planning is very broad. This study does therefore not include factors relating to legal matters, any policies and frameworks with regards to land use and the planned intention of land use or existing zoning schemes. The fact that policies and legislation are import considerations is acknowledged in Chapter 11.
6. The developed pre-feasibility model is semi validated by comparing the model outcomes with that of a previous study. This validation process does however not include the validation of the modelling of air quality.

1.5 Definitions

The concept of *Green Engineering* applied in this study includes the design and use of processes and products in such a manner to minimize negative effects and promote sustainability (US EPA, 2017). Existing green engineering methods are used in the study. The methods included in this study are the use of green roofs, green walls/facades and the planting of trees.

A *pedestrian zone* is a car-free area in cities or towns reserved for pedestrians and sometimes cyclists. There is very little to no automobile traffic, with only a few access points to the area for deliveries or emergencies. Pedestrian zones do not have any parking facilities. According to the Highway Capacity Manual of 2010, a pedestrian zone is a street dedicated to pedestrian use. This can be on a full-time or part-time basis (Transportation Research Board, 2010). For this study it is assumed that the pedestrian zone is on a full-time basis, but will still provide vehicle access for priority vehicles.

A *green pedestrian zone* is an ordinary pedestrian zone where green engineering methods are incorporated. Green engineering methods may include green roofs, green facades, only closing off the area for cars and the planting of trees. Green pedestrian zones can be newly built or can be created in existing areas. Only green pedestrian zones created in existing areas are researched in this study.

2. STUDY METHODOLOGY

In this chapter the steps taken to achieve the study aims and objectives are provided. The study is divided into the following main steps:

1. **LITERATURE REVIEW:** Research based on the current status of the environment and how to address possible environmental problems;
2. **PRE-FEASIBILITY MODEL:** Development of pre-feasibility model to determine the impact of pedestrian zones on the following immediate factors:
    a. Air quality;
    b. Economy;
    c. Social and cultural implication;
    d. Surrounding traffic;
    e. Location specifications;
3. **CASE STUDY:** Evaluating the pre-feasibility model by conducting a case study on the inner town centre of Stellenbosch;
4. **EVALUATION** and **INTERPRETATION.**

The methodology for the LITERATURE REVIEW:

1. Conduct literature research on the current status of the environment and how to address possible environmental problems.
2. The literature research, as presented in Chapters 3 to 6, includes previous studies, environmental problems in South Africa, solutions to stated problems, and pedestrian zones as possible solution to stated problems, existing pedestrian zones and existing green engineering methods.

The methodology for the PRE-FEASIBILITY MODEL:

1. Conduct literature research on methods to analyse the data obtained from previous studies and literature as included in steps one and two of the literature review methodology.
2. Determine the best mathematical approaches to follow in the construction of the pre-feasibility model.
3. Develop mathematical equations.
4. Test the model based on the obtained data (calibration).
5. The steps followed to complete each part of the pre-feasibility model as mentioned in the previous two points above, are elaborated upon in detail in Chapter 7.

The methodology for the CASE STUDY:

1. Test and validate the developed pre-feasibility model. A former study conducted for the inner town centre of Stellenbosch is used as input data.
2. Evaluate the outcomes obtained from the pre-feasibility model by comparing it to the outcomes obtained by the former study. The case study is thus a validation of the pre-feasibility model.

The methodology for EVALUATION and INTERPRETATION:

1. Evaluate the accuracy of the pre-feasibility model based on the validation obtained from the case study and compare the outcomes of the pre-feasibility model to literature.
2. Obtain input and recommendations by presenting the developed pre-feasibility model to industry professionals. This step includes interviews with identified professionals as follows:
    - Me Nina Otto, city and town planner at AECOM;
    - Mr André Pelser, Head of Rate Payers Association Stellenbosch;
    - Me Cara Gerber, transportation and strategic planner at AECOM.
3. Interpret the functioning of the pre-feasibility model based on steps one and two.
4. Elaborate on limitations of the model.
5. Provide recommendations on how to improve the developed model. Include factors which may contribute to the validity of the model and how to address some of the limitations.
6. Discuss other factors that should be addressed provided that a green pedestrian zone has been considered feasible and will be formally implemented.

3. LITERATURE REVIEW: Part 1-Environmental Problems

The literature of this study is divided into three main parts. Literature related to the environmental problems in city centres and methods on how to address these problems are reviewed in this chapter, which is the first part of the literature review. In the second part of the literature review, Chapter 4, the concept of pedestrian zones as a solution to environmental problems is reviewed. Chapter 5, the third part of the literature review, focuses on previous studies and cases of successful pedestrian zones. Thereafter a summary of the literature review is provided in Chapter 6. The layout of the literature review is provided in Figure 3.

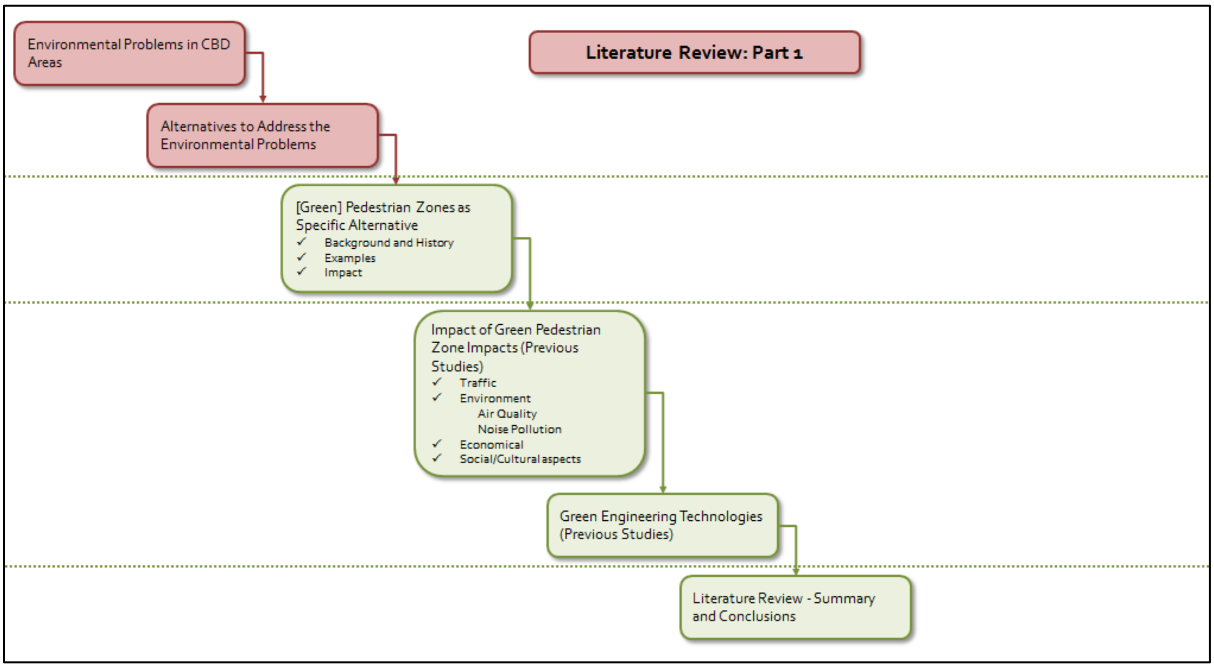

Figure 3: Literature review road map - Part 1

3.1 Current State of Environmental Affairs

The sustainability of cities is often jeopardized by the continuous growth in size and population, leading to a decrease in the quality of life supported in these cities. Constant urbanization can impact the economy and more alarmingly, the environment, by contributing to climate change. Climate change is one of the most worrying environmental problems faced today (CIFF, 2017).

However, if a larger portion of inhabitants perform everyday activities in city centres, instead of moving further out to expanding suburbs, urban sprawling can be reduced. This will lead to less habitat loss, saving green space and ultimately creating a smaller carbon footprint (Suzuki, 2014).

Furthermore, many of the current environmental issues faced around the world can be attributed to overpopulation. Overpopulation is simply defined as the earth being unable to provide for the demand of the large number of humans on earth (Kukreja, 2017). As a result of overpopulation, amongst other effects, water and air pollution occurs, deforestation and urban sprawling take place, wastage increases and resource availability decreases (Kukreja, 2017). Since there is no definite immediate method to resolve the problem of overpopulation, strategies to manage the impacts of the human population on the environment should be put in place (Kukreja, 2017).

3.1.1 Types of Environmental Concerns

The Environmental Performance Index (EPI) measures the ability of a country to safeguard and protect its ecosystems and human health. South Africa was ranked at position 72 on the 2014 EPI (Yale University, 2017). South Africa however downgraded to position 81 on the 2016 EPI rankings.

South Africa is also responsible for the most deforestation in Africa. 17.2% of the tree cover in the country is lost per year, with Swaziland following closely with 16.4% (Yale University, 2017). The following are statistics and opportunities where South Africa can improve on environmental protection (Wonder Plant, 2014):

1. South Africa releases approximately 511 million tonnes of carbon dioxide into the atmosphere each year;
2. The carbon emission in South Africa is 9.18 tonnes per capita per year. This is double the world average of 4.49 tonnes per capita;
3. The carbon emissions due to the consumption of fossil fuels increased by 24% from 1996.

Major environmental problems currently faced worldwide include: (Kukreja, 2017; Nils Zimmermann, 2016)

1. **Pollution**: including air, water and soil pollution with air pollution mainly caused by motor vehicle and industrial emissions, and water pollution caused by acid rain and urban runoff;
2. **Global Warming**: a changing climate as result of human practises such as the emission of greenhouse gases;
3. **Overpopulation**: the fast growth of the population resulting in unsustainable resource levels;
4. **Natural Resource Depletion**;
5. **Increased Waste Disposal**;
6. **Loss of Biodiversity**: extinction of species due to inconsiderate human activities;
7. **Deforestation**: the loss of green cover and trees;
8. **Ocean Acidification**: as direct result of excessive CO_2 production;
9. **Ozone Layer Depletion**: Chlorofluorocarbons corroding the ozone layer;
10. **Acid Rain**: combustion of fossil fuels releasing sulphur dioxide into the atmosphere causing the rainfall to become acidic;
11. **Urban Sprawl**: migration of people from high density urban areas to low density suburban or rural areas;

A detailed discussion of the following environmental concerns is provided in Appendix A:

- Urbanization and Urban Sprawling as Environmental Concern;
- Effect of Urbanization on Green Space;
- Air Pollution as Environmental Concern.

3.2 Possible Solutions to Environmental Issues

With the increase in population size, followed by environmental degradation and increased pollution and often under poor governance, it becomes more urgent to come up with solutions to address all of these environmental problems. The first step is to find ways in which to transform cities to become more resilient and sustainable, to become more inclusive and safe, and finally to become more productive and healthy. Some of the key role players in creating transformed cities include architects, urban planners, engineers and policy makers (Hawley, 2014).

Urban sustainability is the improvement of city life including ecological, economic, social, cultural and political components that will leave no burden on future generations and ensure a healthy environment for all residents. Some of the key actions to contribute to sustainable development are to reduce (Hawley, 2014):

1. Energy consumption;
2. Encroachment on ecological/natural spaces;
3. Usage of harmful building materials;
4. Carbon footprint and to
5. Manage waste better.

Examples are provided in Appendix B on how the above mentioned key actions have been achieved in some cities in terms of (Hawley, 2014):

1. Public Transport;
2. Integrative Urban Design;
3. Waste Management;
4. Biomimicry;
5. Low-Carbon Cities, T-Charge, Congestion Tax and Low Emission Zone Charge;
6. Electric Cars;
7. The Paris Agreement;
8. Green Engineering Technologies;

Detail on the use of Pedestrian Schemes in achieving the above mentioned key actions is provided in section 3.2.1 below and in Chapter 4.

3.2.1 Pedestrian Schemes

A solution to some environmental problems is the implementation of pedestrian schemes. In the city of Chester, England, pedestrianization proved to be advantageous to inhabitants and led to a decrease in environmental degradation, as seen in Figure 4.

Figure 4: Pedestrian zone in Chester, England (WMC Retail Partners, 2017)

In Cologne, Germany, the concentration of carbon monoxide was reduced from 8 parts per million (ppm) to 1 ppm after pedestrianization. The same occurred in Gothenburg, Sweden, where there was a decrease from 35 ppm to 5 ppm (Soni & Soni, 2016). These environmental benefits are primarily related to the removal of traffic. The removal of vehicular movements will contribute to a better micro climate where there is a decrease in dust, noise and the reduction of the urban heat island effect. The planting of greenery on the reclaimed land can also improve the living circumstances of the area by creating space like parks (Soni & Soni, 2016). The pedestrian streets of Schildergrasse and Gothenburg can be seen in Figure 5.

Figure 5: Schildergrasse, Cologne, Germany Pedestrian Zone (left) (Scrivener, 2016) **and Gothenburg, Sweden (right)** (Active Boomer Adventures, 2016)

There are many possibilities on how to address environmental problems. However, in this study the focus will be on pedestrian zones and some green engineering technologies.

4. LITERATURE REVIEW: Part 2-Pedestrianization as Solution

In this chapter pedestrianization as a solution to environmental problems is reviewed in depth as second part of the literature review. Figure 6 illustrates the part of the literature review included in this chapter. In this chapter the origin, value and functioning of pedestrian zones are discussed.

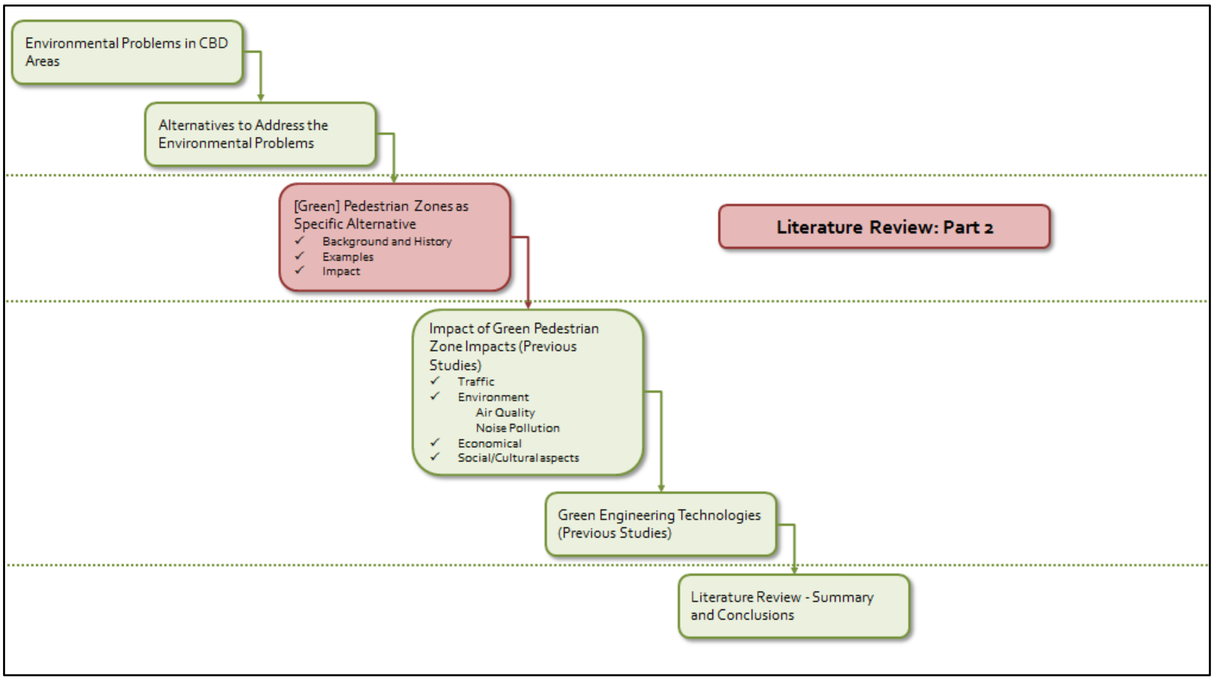

Figure 6: Literature review road map – Part 2

4.1 Background to the Origin of Pedestrian Facilities

The oldest form of transportation is walking. Walking still forms part of the every trip. The beginning and the end of a commute start as pedestrian actions. The concepts of pedestrian zones, pedestrian streets and more importantly, car-free spaces date back to ancient times. The prosperity of ancient cities was often expressed by pedestrian zones in the form of plains, plazas and walkways. Roman cities became known for their pedestrian friendly street designs with elevated sidewalks as seen in Figure 7.

Figure 7: Carriageway with elevated sidewalks in Pompeii, Ancient Roman City (Huxham, 2014)

The Romans also used pedestrian zones to solve problems we are still facing today (Sisman, 2013). These problems included noise pollution caused by vehicles, poor city street aesthetics, congestion, safety concerns and crowding in urban areas. Modification to city streets continued from the age of the animal-drawn vehicle to the Renaissance in the 15th century. After the Second World War, activities in the pedestrianized areas with no automobile access began to increase. This led to Kassel in Germany to become the home of the modern pedestrian zone as known today, and as seen in Figure 8. From this time onwards, Germany and northern European cities continued establishing pedestrian zones (Sisman, 2013).

Figure 8: Pedestrian zone in Kassel (Hoffman, 2017)

Some well-known pedestrian areas include Strøget in the historic centre of Copenhagen, which was declared car-free in 1962 (Figure 9). Carnabary Street in London was converted for pedestrian use only in 1973. Buchanan Street in Glasgow, Scotland banned vehicles in 1978 and is now the epicentre of shopping, architecture and street art in Glasgow (Afar, 2017).

Figure 9: Strøget, Copenhagen (WMC Retail Partners, 2017)

Rapid urbanization and increasing traffic volumes, especially in city centres, restrain people from walking. Any city will benefit aesthetically, socially and economically from providing safe and comfortable traffic free open spaces (Sisman, 2013).

4.2 Existing Pedestrian Zones around the World

A major design aspect of "cities for the future" is the creation of car free living (Riffat *et al.*, 2016). The dependency on cars to commute however became more popular over time. This decreased the quality of life for many people due to long hours spent in congested traffic. People tend to live in suburban areas and work within the urban CBD areas. With a daily commute, in some cases up to two hours, health problems can occur such as stress and even weight gain (Suzuki, 2014). Congestion on most roads is caused by the vehicles within municipality boundaries.

Non-motorized transport, public transport facilities, adequate pedestrian and cycling infrastructure can be implemented as solution to the problem of vehicular commutes and time spent in congestion. Development policies in urban areas should also encourage for at least 50% of urban activities to be within 1km of residential areas. This will make it possible to rely on smaller and more fuel efficient cars (Sustainability Institute, 2012).

In this section some examples of where pedestrian zones are used to minimise the reliance on cars, are investigated.

4.2.1 Super Blocks in Barcelona, Spain

In the City of Barcelona, Spain, a new strategy was implemented to restrict vehicular traffic to only major roads and converting secondary roads into pedestrian streets where citizens can live in leisure with the added benefit of reduced pollution (Bausells, 2016). The city developed this mobility plan to reduce traffic by 21% in order to address the excessive levels of noise and air pollution (Bausells, 2016).

Superilles (superblocks) are small square neighbourhoods, together forming a grid as seen in Figure 10. These blocks were originally engineered to spread out the population evenly and to provide all with a green space in the centre of the block to ultimately contribute to public health. Due to urban development the initial idea to prohibit cars from the superblocks failed and so the superblocks got filled with cars. From there the high noise and air pollution levels originated (Bausells, 2016).

Figure 10: Superblocks in Barcelona (Bausells, 2016)

A superblock consists of nine smaller blocks. By redirecting the traffic around the superblocks to only travel along the perimeter and removing cars from the centres of these blocks, 60% of streets were freed up for pedestrian use. Vehicles would only be allowed to enter the in-between streets if they were residents or business providers and at a reduced speed of 10km/h (Bausells, 2016). The traffic flow configuration can be seen in Figure 11, where the roads indicated in green form part of the network closed for vehicular traffic.

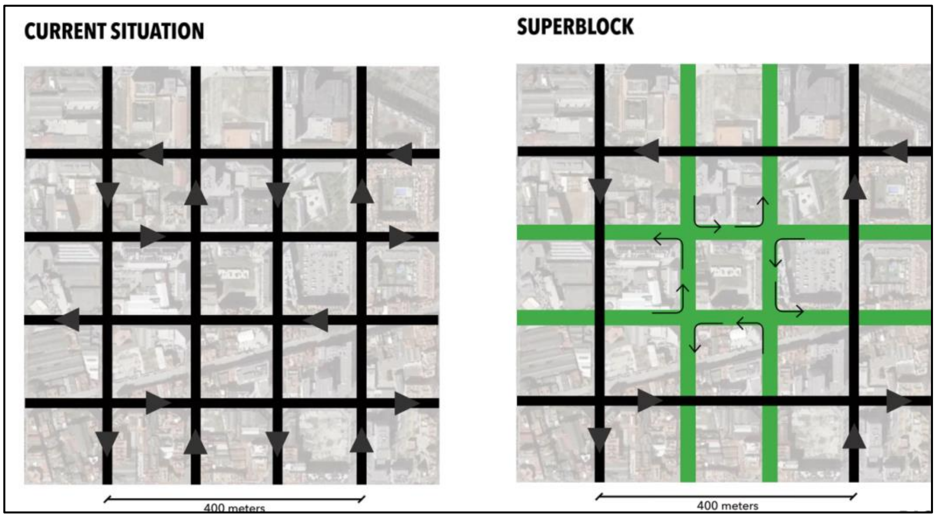

Figure 11: Traffic flow around Superblocks (Bausells, 2016)

The city planned to complement this project by promoting the use of public transport, walking and the use of bicycles. This aim was achieved by adding a bus network to the major roads and by the introduction of 300km of bicycle lanes. Ultimately, the city aimed to provide public transport access within 300 metres and at an average waiting time of not more than 5 minutes for anyone, anywhere within the superblocks (Bausells, 2016).

4.2.2 NYC: Times Square and the Highline

Times Square in New York is one of the city's most popular destinations for locals and tourist alike. Time Square is home to a plenty of cafés, restaurants and boutiques and serves as the venue for various events such as music concerts, New Year celebrations and carnivals. It therefore came as no surprise that pedestrian crowding become synonymous with the square. Some of the problems faced included (Design Trust for Public Space, 2018):

1. Overcrowded and congested sidewalks;
2. High volumes of pedestrians;
3. No room to walk, except in the streets;
4. Crowding during day and night;
5. Disorganized streets;
6. Unnecessary obstacles, planters, structures and barricades, filling the already limited space;
7. Vendors using the sidewalk as "showroom".

Level of Service (LOS) is a qualitative measure to determine the performance of the service, with "A" being adequate and good and "F" indicating congested circumstances (Transportation Research Board, 2010). During a survey in 2014 with 2350 local employees at New York Times Square, 68% complained about the poor LOS, which was then at level D within the square and which would cause them to consider employment elsewhere (Goldwyn, 2014).

Broadway Street and Seventh Avenue at Times Square intersect at a diagonal to form a bowtie-shaped crossing. This area is therefore also known as the "Bowtie" (Design Trust for Public Space, 2018). The amount of vehicle-pedestrian collisions in the square was another problem caused by the restricted pedestrian space. Figure 12 presents the collision counts for the years 2002, 2003 and 2004 at various points around the "Bowtie".

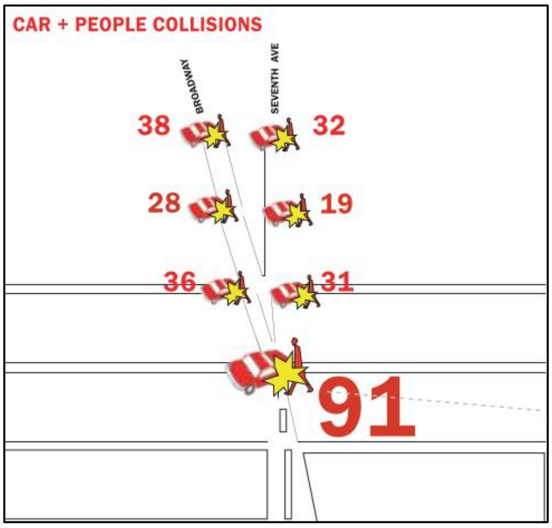

Figure 12: Vehicle-Pedestrian collisions in Bowtie (Design Trust for Public Space, 2018)

With 89% of the space in Times Square allocated to vehicles and 11% to pedestrians, even though pedestrians made out 90% of the users of the area, the city of New York realised that the utilisation of the existing space should be revisited (Goldwyn, 2014).

The process of providing solutions to the abovementioned problems captured thoughts such as creating a place where people WANT to be and re-thinking the relationship between pedestrians and vehicles. Even though the solutions did not involve the removal of all vehicular traffic, the vehicular flow through the area was balanced and redirected to some of the surrounding streets. This was done to free up more space for pedestrians and to increase the sidewalks around the Bowtie. Signals were timed to provide more green time for pedestrians. The spatial distribution between the different modes within the area changed and more pedestrian areas were created. This can be seen in Figure 13 where spaces initially allocated as roadway were transformed to pedestrian space.

Figure 13: Time Square before (left) and after (right) pedestrianization schemes (Goldwyn, 2014)

4.2.3 Copenhagen Bicycle Friendly City Centres

Copenhagen, Denmark, is one of the most famous bicycle and pedestrian orientated cities in Europe. As with many other cities in Europe, while the traffic congestion increased, the number of parking spaces increased and the conditions for pedestrians deteriorated. This resulted in the pedestrianization of the main street, Strøget, on the 17th of November 1962. The new car free area became popular with the local residents from the first day and proved to be a success, even though scepticism was initially high.

Today, over 96 000m^2 of Copenhagen is car-free with 33% allocated to streets and 67% to city squares. The city centre became more attractive and is used for multiple purposes such as festivals, outdoor ice skating in the winter, music concerts and a gathering spot for social and cultural activities. The city managed to create these car-free spaces by limiting the number of parking spaces, reducing the number of car lanes in several main roads, restricting through traffic and by developing public transport facilities. In 2004, 80% of all journeys were made per foot and 14% by bicycle (Wallztrom, 2004). In Figure 14 the transformation of the city can be seen. The blue indicates the car-free zones and how the car free space increased from 1962 (only 15 800m^2) to 1996 (95 750m^2).

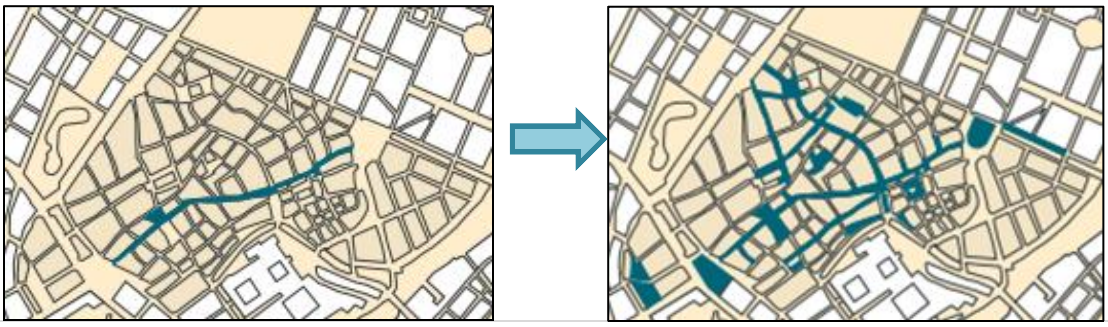

Figure 14: Transformation of Copenhagen (1962 to 1996) (Wallztrom, 2004)

4.3 Green Spaces and Pedestrian Zones in South Africa

There is a growing trend in population and vehicle volumes in South Africa. The population grew by almost 4 million people over a period of five years. The population was 51 770 560 million in 2011 and increased to 55 653 654 million in 2016 (StatsSA, 2017). The July 2018 estimates of the United Nations give the population of South Africa to be 57.4 million of which 62.9% is urban (Worldometers, 2018). According to the National Administration Traffic Information System (NATIS) a total of 12 027 860 vehicles were registered at the end of February 2017. At the end of December 2016, 11 964 234 vehicles were registered. A month later, at the end of January 2017, the vehicle count increased to 12 009 553. This is an increase of 45 319 vehicles. The major cities of South Africa contain more than half of the registered vehicles. There are currently 4 643 741 registered vehicles in Gauteng, 1 935 054 in Western Cape and 1 607 946 in KwaZulu-Natal (Van der Post, 2017). This growth in vehicle volumes and growth in population place strain on the natural environment and open spaces within cities.

Potential threats to retaining urban green spaces in South Africa are business park developments, housing developments and transportation projects. Pertinent currently in South Africa is the unlawful establishment of informal settlements within metro and municipal borders with Vrygrond in Cape Town as an example (Dullah Omar Institute, 2016).

The map of South Africa is provided in Figure 15 with city and town boundaries, built-up areas and parks displayed as different coloured overlays. From this map an overview of the current status of green spaces in South Africa can be derived. Similarly, on a regional level, Figure 16 provides an overview for the Cape Peninsula and surrounding areas. The Open Source QGIS Geographical Information System (GIS) software program (QGIS version 3.2) was used to plot and process MapIt shapefile data to create Figure 15 and Figure 16.

With built-up areas covering approximately 2.4% (as calculated with the QGIS tool based on MapIt data) of the 1,219,912 km^2 South African land area (Worldometers, 2018), it means that on average the urban density for the more than 36 million city and town dwellers [62.9% of the 57.4 million total population (Worldometers, 2018),] is calculated at 1233 persons per km^2 .

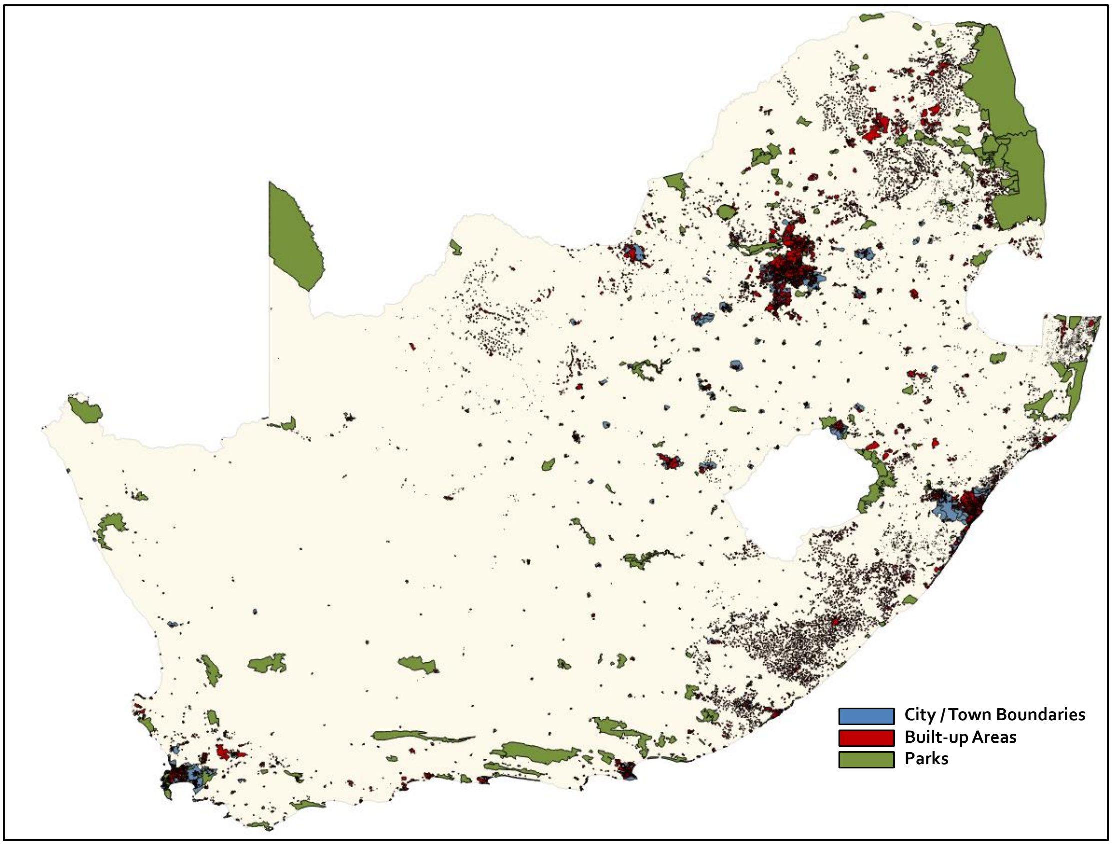

Figure 15: Map of South Africa showing city/town boundaries, built-up areas and parks

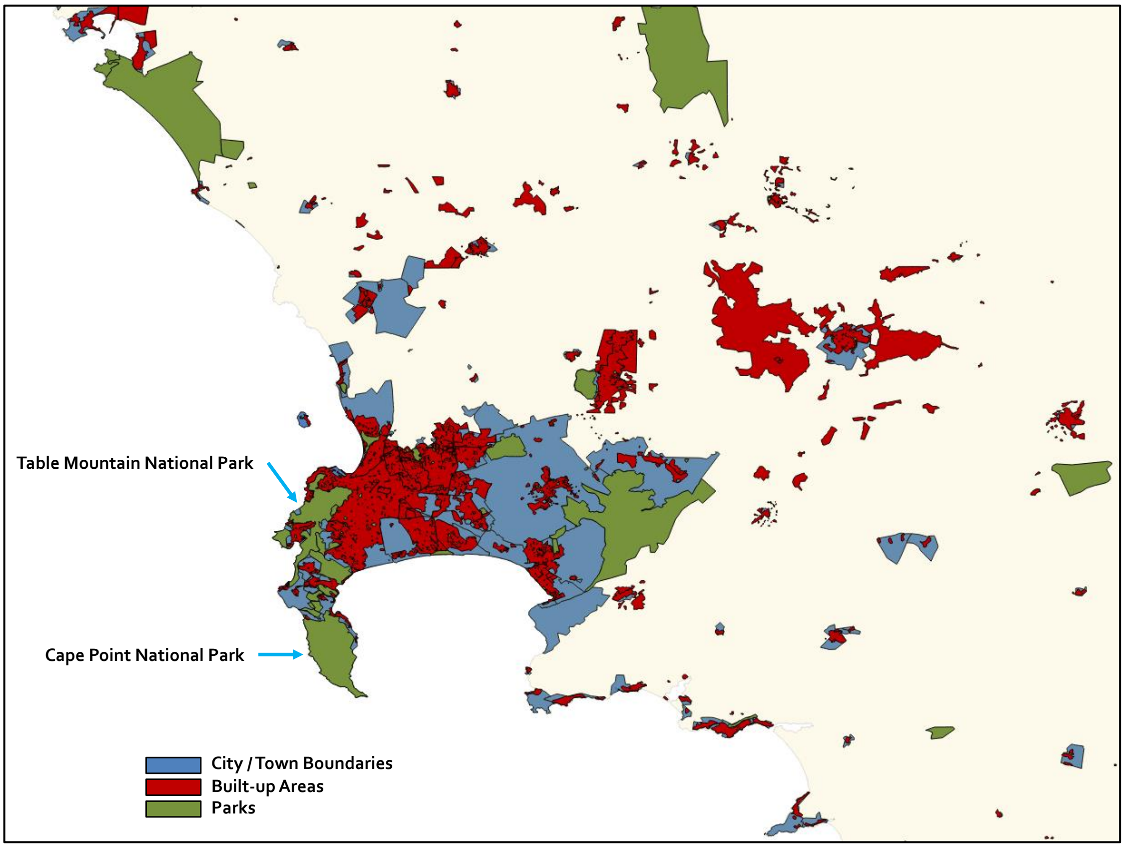

Figure 16: Cape Peninsula and surrounding areas

QGIS provides a number of useful features to process GIS data. These features include the ability to create a new overlay from overlapping overlays. Another feature is to calculate areas within an overlay and to export an overlay as a spreadsheet. Utilising these features, the map in Figure 17 was created to demonstrate the different areas in the Cape Town area.

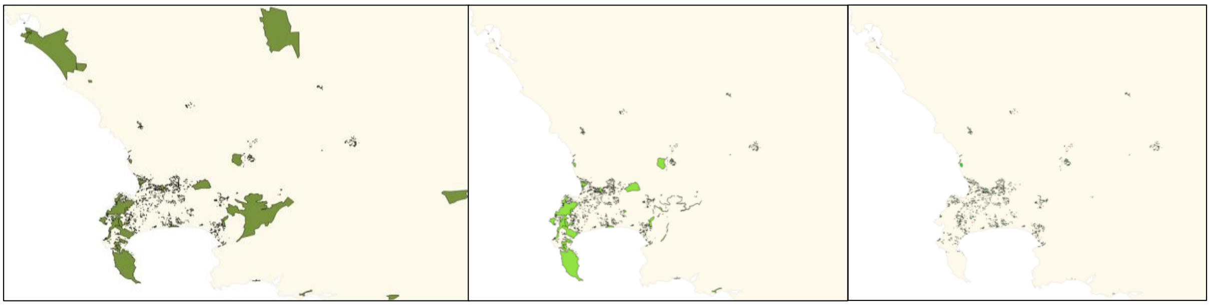

Figure 17: Cape Peninsula and surrounding areas: park areas (left), park areas in city / town boundaries (centre) and park areas within built-up areas (right)

Further, by utilising these features, the statistics as provided in Table 1 were also derived. The value for green space per capita as calculated and listed in Table 1 is compared with published values and is graphically presented in Figure 18. From Figure 18 it is noted that South Africa ranks on the lower end.

Table 1: Statistics related to green spaces in South Africa

Area	Coverage	Source
Park Areas	5.354% of South Africa	QGIS calculated (MapIt data)
Built-Up Areas	2.400% of South Africa	QGIS calculated (MapIt data)
City / Town Boundaries	2.214% of South Africa	QGIS calculated (MapIt data)
Parks in City / Town Boundaries	0.17% of South Africa	QGIS calculated (MapIt data)
Parks in City / Town Boundaries	4.85% of City / Town Boundaries	QGIS calculated (MapIt data)
Parks in Built-up Areas	0.052% of South Africa	QGIS calculated (MapIt data)
Parks in Built-up Areas	2.21% of Built-up Areas	QGIS calculated (MapIt data)
South African size (published)	1 219 912 km^2	(Dullah Omar Institute, 2016)
South African population (published)	57.4 million	UN estimation (Worldometers, 2018)
South African urban population (published)	62.9%	UN estimation (Worldometers, 2018)
Park area	65 314 km^2	QGIS Calculated (MapIt data)
Park area per capita	1138 m^2	QGIS Calculated (MapIt data)
City / Town area	27 008 km^2	QGIS Calculated (MapIt data)
City park area	1309 km^2	QGIS Calculated (MapIt data)
City park area per capita	36 m^2	QGIS Calculated (MapIt data)
Urban (built-up) area	29 273 km^2	QGIS Calculated (MapIt data)
Urban (built-up) park area	528 km^2	QGIS Calculated (MapIt data)
Urban (built-up) park area per capita	17 m^2	QGIS Calculated

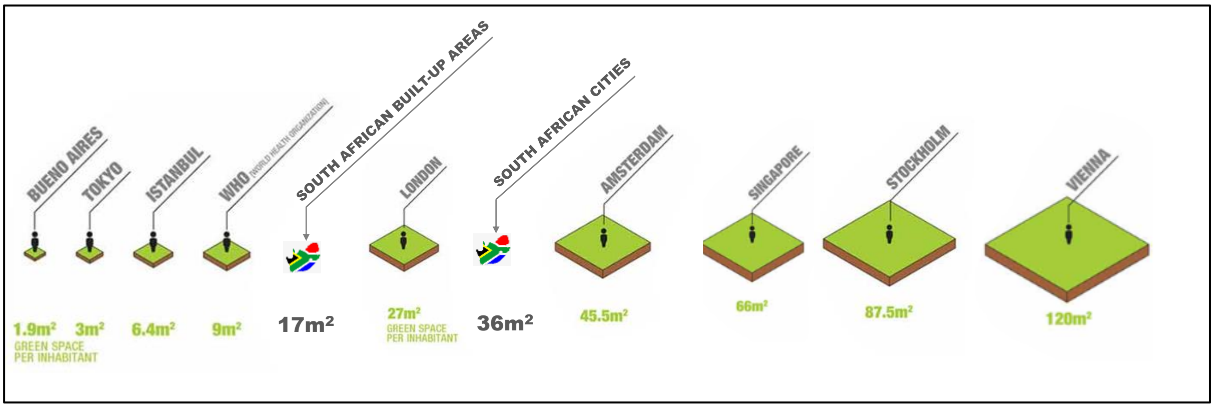

Figure 18: Green space per capita (RSA park areas excluding GPZs) (Baharash Architecture, 2018)

The Cape Town Green Map initiative was founded in 2009 in preparation for the 2010 Soccer World Cup, building on the success of Germany's 2006 model and takes into account the impact on the environment of such a huge event (Green Map, 2018).

The Cape Town Green Map is one of multiple projects, focusing on greening initiatives, carbon reduction and offset, water conservation, sustainable transport, integrated waste management, biodiversity awareness, green procurement, responsible tourism and environmental awareness (Baharash Architecture, 2018). From Green Maps, significant green zones of interest for Cape Town are presented in Figure 19. An extract from the Cape Town Green Map is provided in Figure 20.

Figure 19: Cape Town pedestrian zones (Green Map, 2018)

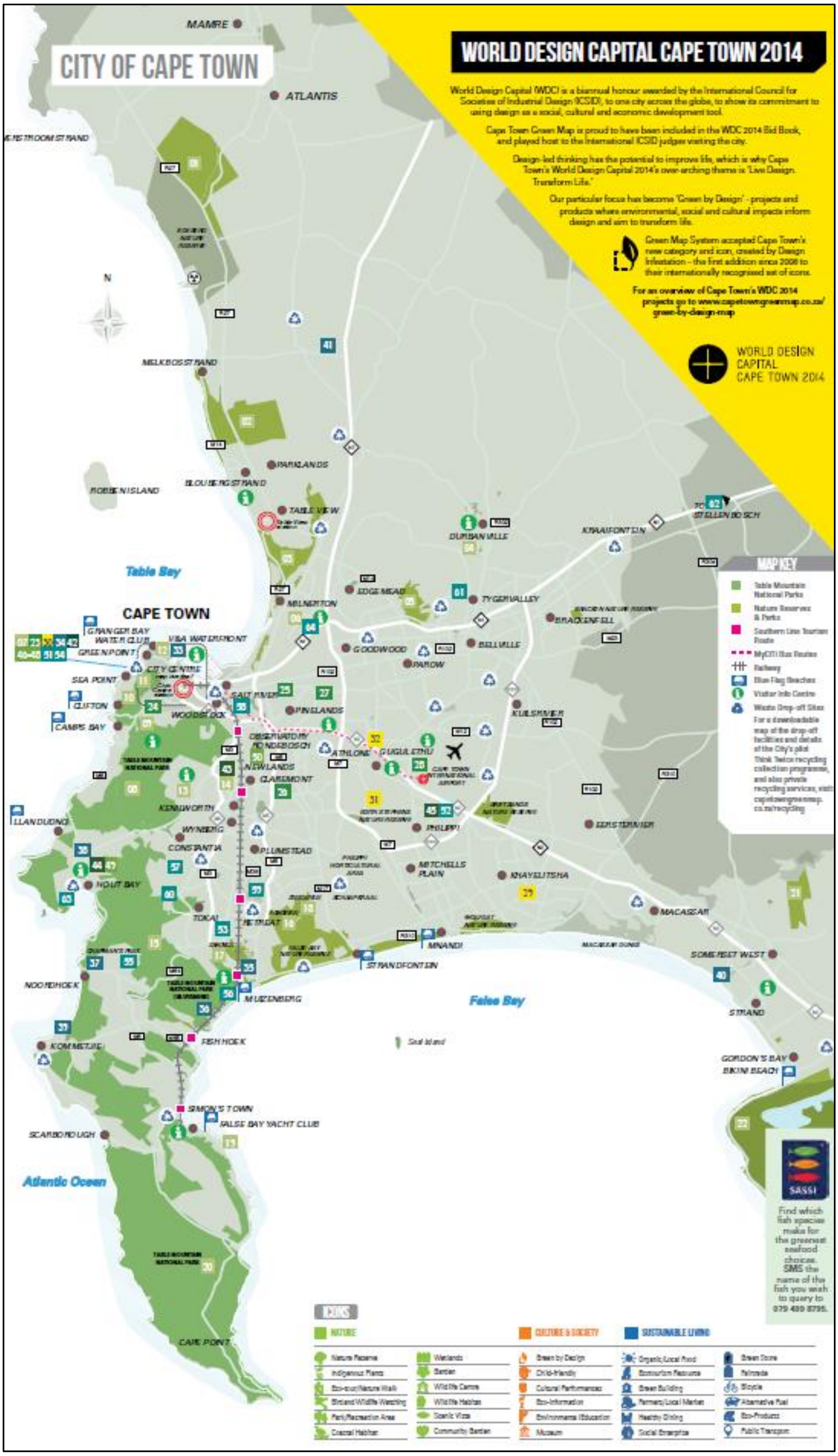

Figure 20: Extract from Cape Town Green Map (Baharash Architecture, 2018)

4.4 How Pedestrian Zones and the Environment Fit Together

In this section the operations, advantages and disadvantages of pedestrian zones and the impact of pedestrian zones on the environment are discussed.

4.4.1 Why a Green Pedestrian Zone?

By creating a green pedestrian zone in city or town areas with a high density, the amount of green space per capita will increase. This will lead to higher quality of living environment (Lee *et al.*, 2015).

The flowchart in Figure 21 illustrates the positive consequences in environmental safeguarding caused by the creation of green pedestrian zones. As consequence, at least 7 of the 12 major high-priority environmental problems faced today (as described in paragraph 3.1.1) will be reduced.

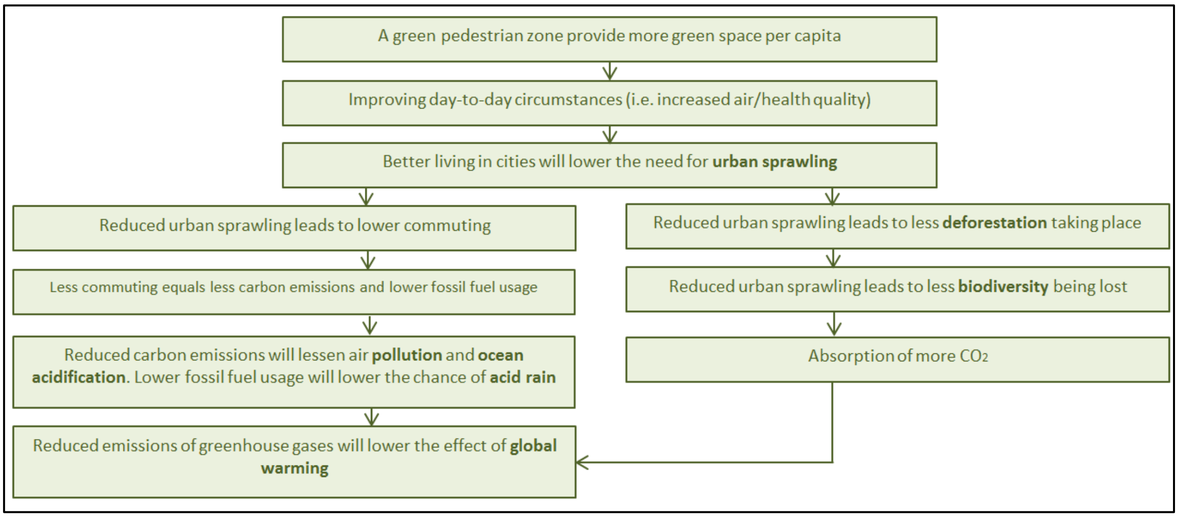

Figure 21: Positive consequences associated with GPZs

In order to create a GREEN pedestrian zone, existing green engineering methods are introduced to the area. With the implementation of green roofs and walls or facades, urban runoff will be reduced, hence less water pollution. Green roofs and walls or facades conserve energy, support lower air pollution, reduce carbon emissions, promote urban cooling and provide a habitat for insect biodiversity (GreenWall_Australia, 2014).

Green paving solutions can also be used in the area. Solutions can include solar reflective coatings on existing pavements to reduce heat, permeable pavers to manage storm water or eco-friendly concrete alternatives (Rose Paving LLC, 2017).

4.4.2 Advantages of a Green Pedestrian Zone

Not only will the environment benefit from green pedestrian zones but also the local community which include residents, retailers and restauranteurs. The increased attractiveness of a pedestrianized environment will promote walking as a mode of travel and therefore increase the number of pedestrians making use of the pedestrianized area. An awareness and appreciation of the historic environment of the city or town will be created. It is anticipated that a traffic-free zone will induce an increase in property value and other economic and business activities (increased retail turnover) due to more tourists and shoppers being attracted to the zone (Chiquetto, 1997).

The primary benefits associated with pedestrian zones can be divided into four main groups namely (Blaga, 2013):

1. *Health* benefits;
2. *Social* benefits;
3. *Environmental* benefits;
4. *Economic* benefits.

These benefits are described in the following sections.

1. ***Health Benefits:***

By creating green pedestrian zones in city centres the amount of urban green space will increase. Urban green spaces can be defined as any public accessible open spaces in an urban setting, typically covered with greenery such as parks. The increasing urbanized living and the contemporary lifestyle associated with urban spaces are linked to public ***health*** issues such as depression. A United States study found that residents living near a green space feel less stressed and are physically more active due to the cleaner and greener environment. Urban green spaces therefore have a direct relationship with the quality of life and wellbeing of urban dwellers (Lee *et al.*, 2015).

2. ***Social Benefits:***

The use of an urban green space is mainly dictated by the size of the space. Some of the main uses include physical activity, social interaction and relaxation. The accessibility of an urban green space is the primary factor determining the usefulness of any green space. An important design feature of any urban green space should be the sense of community, coherence and safety. These factors are linked to the ***social*** benefits associated with any green space. The most important consideration should however be that the space is useable since the health benefits obtained from an urban space are due to the use of the space rather than from its presence (Lee *et al.*, 2015).

The sense of safety contributes to the social benefit of pedestrian zones. By designing pedestrian spaces to be public spaces, the natural sense of surveillance is created spontaneously. This principle forms part of the concept: *"crime prevention through environmental design"* (Space, 1972). Well-designed pedestrian spaces are attracting interest from inhabitants of neighbourhoods, assisting in crime prevention. The sense of a secure space is created by the users of the space realising that any actions happening in the area will be noticed and acted upon through the *"eyes on the street"* principle. This idea demotivates criminals to enter spaces with this characteristic (Cabe, 2018.). Pedestrian zones also prevent vehicular use in the area and eliminate the possibility of criminals making use of a "get-away-car." It was also found that criminals are likely to perform criminal activities where there are easy escape and through routes. Pedestrianization will eliminate vehicular through routes in the area (Frith *et al.*, 2017).

Another social benefit is that fewer accidents involving pedestrians will occur. The travel mode used in central and high density areas, such as main shopping streets, is predominantly walking. Currently most of the accidents where pedestrians are involved occur in urban areas. In South Africa 1 out of 10 pedestrians involved in collisions with cars on urban roads are killed. The statistics of pedestrian fatalities in South African cities are compared to other cities in Figure 22. From this data it is interesting to observe that all of the South African cities have higher pedestrian fatalities than the global average. The South African cities included in the dataset are Pretoria, Durban, Johannesburg, Cape Town, Port Elizabeth and Bloemfontein. It is interesting to note that the most fatalities occur in

Bloemfontein (Ribbens, 2017). By transforming such areas to be only accessible to non-motorized traffic, pedestrian safety will be promoted resulting in ***less pedestrian accidents***.

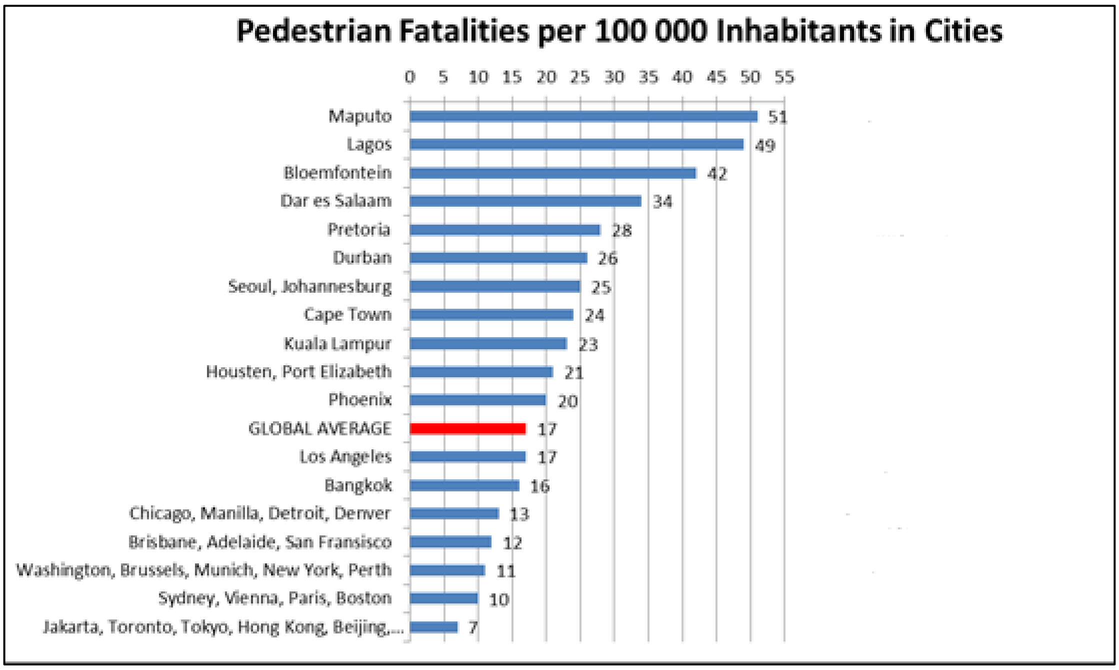

Figure 22: Pedestrian Fatalities in Cities (Ribbens, 2017)

3. Environmental Benefits:

The environment will improve in terms of aesthetics and lower local air and noise pollution through the introduction of green pedestrian zones. Other ***environmental*** benefits associated with urban green spaces are a reduction in the urban heat island effect, which in turn reduces energy costs to cool buildings, minimizing of air, water and noise pollution, absorption of CO_2 greenhouse emissions and a reduction of urban runoff (Lee *et al.*,2015).

4. Economic Benefits:

The effects of traffic-calming and pedestrian schemes implemented in Germany and the UK on retailing were researched. It was noted that the shops situated inside the pedestrianized areas were more successful than those situated outside of the pedestrianized areas. It can therefore be concluded that the implementation of pedestrianization schemes can have positive ***economic*** benefits (Hass-Klau, 1993a).

5. Other Benefits:

In the past the main objective in the planning of cities was to maximise the flow of traffic and pedestrians were not a priority. With increased congestion and vehicles having right of way in most city centres, the cities became “dead places” from a social point of view. Some authors describe these vehicle orientated streets as “killed by vehicles” (Soni & Soni, 2016). Due to limited space available in city centres as socio-economic systems, the only feasible solution to upgrade the environment and mobility in these areas is pedestrianization. This method has been applied in some of these pedestrian inaccessible places and contributed in the revitalization of these city centres (Soni & Soni, 2016).

Most of the successful pedestrianized areas and pedestrian orientated cities are located in Europe. With Europe situated in the Northern Hemisphere the continent is associated with colder temperatures and more rain. It can therefore be concluded that weather does not have a significant impact on the use of pedestrian areas.

4.4.3 Disadvantages of a Green Pedestrian Zone

Some of the disadvantages associated with pedestrian zones include:

1. *Negative Traffic Impact;*
2. *Negative Accessibility Impact;*
3. *Negative Economic Impact.*

1. *Negative Traffic Impact*

In some cases pedestrianization worsened traffic flows in surrounding areas with increased travel time and fuel consumption (Chiquetto, 1997).

2. *Negative Accessibility Impact*

Pedestrianization can decrease the accessibility of an area to car users and discourage car users to travel to the specific pedestrian zone, especially in the case where the traffic-free zone is situated far from other activity centres (Chiquetto, 1997).

3. Negative Economic Impact

Due to the inaccessibility in some cases, property devaluation and poor retail turnover can occur (Chiquetto, 1997). Therefore, careful location planning for any pedestrianization scheme is of high importance.

The location characteristics and boundary conditions for a suitable area to be converted into a pedestrian zone are provided in Chapter 7 as part of the pre-feasibility model. Additional costs will have to be covered by local municipalities or communities in order to create any pedestrian zone or green pedestrian zone.

5. LITERATURE REVIEW: Part 3-Previous Studies

This section of the literature review covers previous studies which have been conducted in the field of pedestrianizing and the creation of vehicle free areas as illustrated in Figure 23.

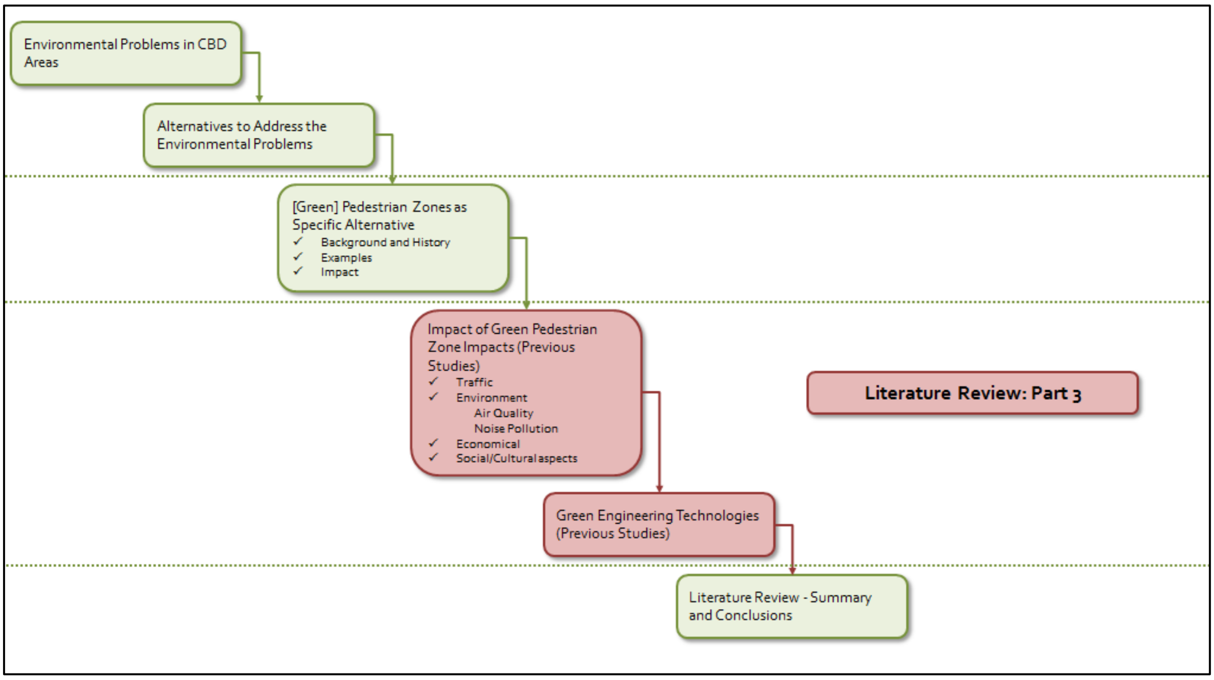

Figure 23: Literature review road map: Part 3

The information obtained from previous studies is divided into the following categories:

1. The effects of pedestrianizing on air quality;
2. The effects of pedestrianizing on noise pollution;
3. The economic benefits for restauranteurs and shop owners within a pedestrianized area;
4. The effects of green spaces and pedestrianized areas on quality of life and human wellbeing (social benefits);
5. The impact of pedestrianizing on the traffic within the surrounded network;
6. Optimised locations for pedestrianized zones;
7. The effect of green engineering methods on the environment (with the inclusion of green roofs and green walls/facades).

The above mentioned 7 points are discussed in detail in Appendix C. The literature and the outcome of these previous studies were consulted and analysed to obtain specific empirical values for the variables included in the pre-feasibility model. These values are processed to a format suitable to derive the postulated pre-feasibility model as presented in Chapter 7.

6. LITERATURE REVIEW: Part 4-Summary and Conclusions

This is the final chapter of the literature review as illustrated in Figure 24. In this chapter the main conclusions drawn from the literature review are summarized.

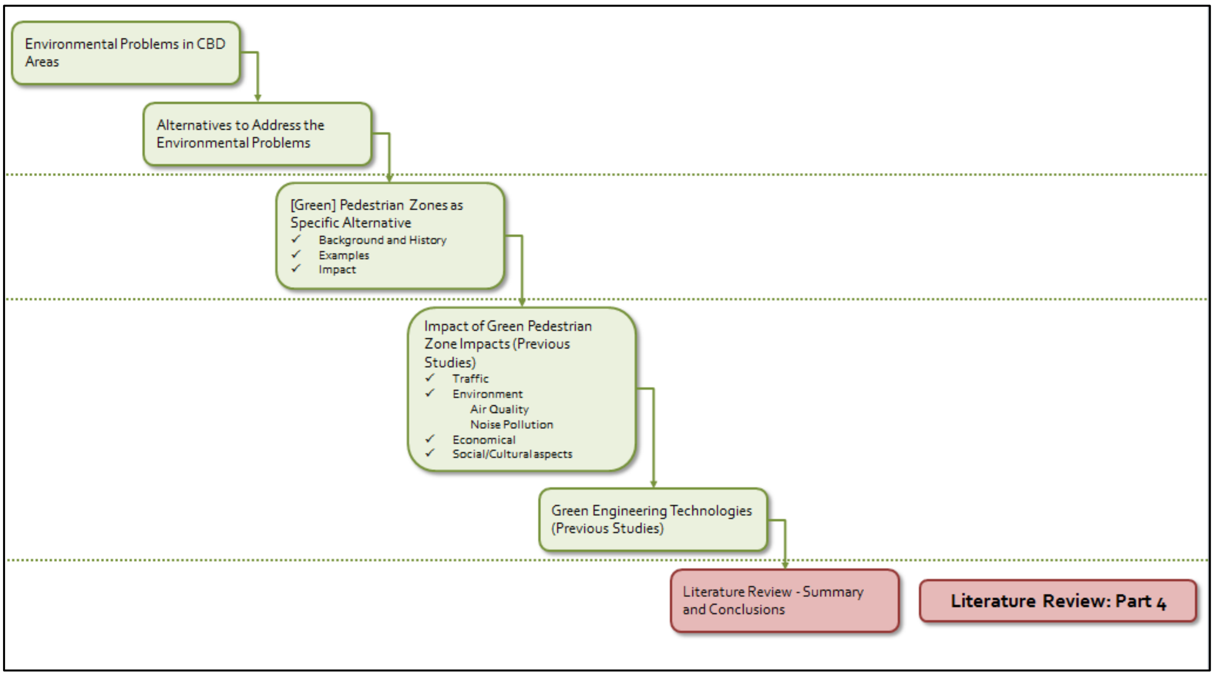

Figure 24: Literature review road map-Part 4

The conclusion that can be drawn from the first two parts of the literature review is that environmental problems do exist. There are however many methods to mitigate and reduce some of the problems. South Africa is no exception and should also implement strategies on how to address environmental problems. Some of the major environmental problems currently of concern include air pollution, urbanization and climate change. A possible solution to these problems can be the implementation of pedestrian areas in city centres.

In the third part of the literature review successful pedestrian zones have been researched. The results obtained from the previous studies will be analysed to create the proposed pre-feasibility model. The main conclusions drawn from the previous studies, as discussed in Chapter 5 and Appendix C, are summarized in Table 2. From the previous studies the following main reasons for pedestrianization were identified:

1. Environmental degradation in terms of poor air quality, noise pollution and health scares associated with air pollution;
2. Old architecture degradation due to air pollution;
3. Residents living in some of the areas were confronted with high levels of traffic passing through their living area;
4. Pedestrian and vehicle collisions;
5. High levels of congestion;
6. Traffic negatively impacting areas with high pedestrian, tourist or student activity;
7. Poor quality of life for residents in dense and traffic prone areas.

Table 2: Summary of previous studies

Finding	Example Cities	Sources
Pedestrianization of an area improves the environment -Reduction in levels of air pollutants was noticed after the implementation of pedestrian schemes	• Chester • Nuremburg • Oxford • Cambridge • Istanbul • Katerini • Rhodes	(Wallztrom, 2004); (Brebbia, 2000); (Üzümoğlu *et al.*, 2015); (Chiquetto, 1997)
Pedestrianization reduces noise pollution	• Durham • Leeds • Chester	(Chiquetto, 1997)
Pedestrianization has a positive effect on the retail within the pedestrianized area -Increase in turnover recorded	• Cambridge • Istanbul • Seville • Kajaani	(Wallztrom, 2004); (Üzümoğlu *et al.*, 2015); (Castillo-Manzano *et al.*, 2014)
Pedestrianization led to an increase in the use of public transport	• Wolverhampton • Oxford • Ghent	(Wallztrom, 2004);
Pedestrianization holds social benefits -Increase in the perception of the environment, feeling of safety and overall feeling of area recorded	• Cambridge • Kajaani • Ghent • Seoul • Seville	(Wallztrom, 2004); (Castillo-Manzano *et al.*, 2014); (Soni & Soni, 2016)
Pedestrianization does not have severe effects on the traffic of the surrounding network -Traffic evaporation has been experienced in certain cities	• Chester • Rhodes • Katerini • Nuremburg • Cambridge • Oxford	(Chiquetto, 1997); (Brebbia, 2000); (Wallztrom, 2004);
Effect of green roofs and facades -Reduction in noise pollution -Absorption of air pollutants	• Chicago • Toronto • Hong Kong	(Yang *et al.*, 2008); (Currie & Bass, 2008); (Li *et al.*, 2010)

It is important to evaluate the environmental impacts of pedestrianization and traffic management schemes by comparing the circumstances of the scheme "before" and "after" implementation (Brebbia, 2000). There is however a limited number of studies that provide "before" and "after" values.

7. CONSTRUCTION OF PRE-FEASIBILITY MODEL

In this chapter the construction of the pre-feasibility model is presented. The aim is to develop a pre-feasibility model that will enable decision makers to determine whether an identified area will suffice as a pedestrian area.

The pre-feasibility model is compiled in two parts. The first part is a suggested checklist to determine the feasibility of the identified location for a planned pedestrian zone. The concept of mathematical modelling is used to construct the second part. The second part will further aid in determining the possible benefits that can be expected from the planned pedestrian zone. The factors affected by the installation of a green pedestrian zone addressed in this study include:

1. Location of green pedestrian zone — Part 1: Suggested Checklist
2. Air quality
3. Economic Impacts
4. Social Impacts
5. Traffic Impacts

(Items 2–5: Part 2: Mathematical Model)

7.1 Pre-Feasibility Model Part 1: Location Determination

In this section the development of the first part of the pre-feasibility model is discussed. This includes the main reasons for creating a pedestrian zone and the location characteristics associated with a successful pedestrian zone.

7.1.1 Location Characteristics of Successful Pedestrian Zones

Previous studies have been consulted in determining the abovementioned characteristics. It is found that pedestrian zones are ideally placed in areas where constrained pedestrian space is available and driving in this specific area is associated with an unpleasant experience. These areas are typically within a shopping district and where both vehicle volumes and pedestrian volumes are high. The location of a pedestrian zone will typically be in a busy city or town centre. Table 3 provides a summary of eleven existing pedestrian zones and the location characteristics associated with each.

Table 3: Location characteristics associated with pedestrian zones

Pedestrian Zone	Location Characteristics	Source
Pedestrianization of Times Square in New York City	• Overcrowded sidewalks • Plentiful on-street retailers, vendors and cafés present • High level of accidents involving pedestrians	(Design Trust for Public Space, 2018)
Pedestrianization in Chester and Nuremburg	• Located in central streets of historic town • Location was prone to congestion before pedestrianization	(Chiquetto, 1997) (Wallztrom, 2004)
Pedestrianization in Kajaani and Wolverhampton	• Located in central main streets and main squares of historic town • Congested prior to pedestrianization	(Wallztrom, 2004)
Pedestrianization in Oxford	• Located in High Street, one of the main shopping streets	(Wallztrom, 2004)
Pedestrianization in Cambridge	• Located in central streets of historic town • Located where high volumes of students and tourists were present • Located in old and narrow streets	(Wallztrom, 2004)
Pedestrianization of Historic Peninsula of Istanbul	• Located in central commercial area • Dense residential area • High volume of tourists • Removed bus routes through pedestrianized area	(Üzümoğlu *et al.*, 2015)
Pedestrianization in Katerini	• Located in central commercial area • Dense residential area • High traffic volumes prior to pedestrianization	(Brebbia, 2000)
Pedestrianization in Rhodes	• Located in central commercial area • High tourist volumes	(Brebbia, 2000)
Pedestrianization in Seville	• Located in central commercial area • High volume of pedestrians • Congested prior to pedestrianization • Very noisy before pedestrianization	(Castillo-Manzano *et al.*, 2014)

In Table 4 these characteristics are analysed according to the frequency of the location characteristic being present. It can be assumed that the higher the occurrence of this characteristic, the higher the importance of this characteristic is for the success of a pedestrian zone.

Table 4: Location characteristics ranked according to occurrence

Location Characteristic	% occurrence
Located in central streets of historic town	11/11 = 100%
Congested prior to pedestrianization	6/11 = 54.5%
Overcrowded sidewalks / high pedestrian levels	5/11 = 45.5%
Dense residential area	2/11 = 18.2%
High level of accidents involving pedestrians	1/11 = 9%
Located in old and narrow streets	1/11 = 9%
Removed bus routes through pedestrianized area	1/11 = 9%
Very noisy before pedestrianization	1/11 = 9%

A study in Lithuanian cities was conducted to determine the criteria for a successful pedestrian zone from the view of the users of the area. The main objectives of creating a pedestrian zone are to separate pedestrians from vehicles and to provide a safe and comfortable environment within a city centre. Overall, the research suggests that social, economic and environmental criteria should be met in order to guarantee the vitality of a pedestrian zone and to improve the quality of life for residents. The results were obtained by surveying 100 inhabitants of three cities, namely Vilnius, Kaunas and Klaipeda. The surveyed inhabitants were provided with a list of criteria which they were to rate from most important to least important. The results are presented in Table 5 (Dičiunaite-Rauktiene *et al.*, 2018). The criteria are grouped as environmental, social or economic criteria. The criterion ranked as number 1 is considered the most important and number 20 the least important.

Table 5: Survey results for the characteristics of pedestrian zones

Criteria Category	Criteria Description and Rank
Social Criteria	1-Accessible parking (in terms of distance) 2-Residential area: apartments, hotels and homes 3-Comfortable and safe space for pedestrians 6-Accessibility via public transport 9-Safety and low crime rates 10-Night-time street lighting 11-Comfortable and safe space for cyclists 12-Cultural space: aesthetic appearance for the streets and buildings, architectural and cultural heritage monuments and their preservation 13-Space adapted for relaxation and recreation 16-Promoting healthy lifestyle: space for cyclists, athletes and people who engage in other types of active leisure 17-Developing communities: spaces for meetings and interaction 20-Entertainment: attractive space for entertainment, culture, art projects, city festivals, fairs and other events.
Environmental Criteria	4-Air pollution: protection against road transport pollution 5-Noise protection against vehicle noise 7-Presence of trees and green zones
Economic Criteria	8-Tourism development 14-Incentives for small and medium businesses 15-Commerce and meeting visitors' needs 18- Job creation 19-Customer friendly parking and parking prices

In previous studies, especially with the implementation of pedestrianization schemes in Katerini and Rhodes in Greece, it was found that the following considerations should be included when planning a pedestrianization scheme (Brebbia, 2000) (Hass-Klau, 1993a):

1. High pedestrian volumes will be accommodated in the central areas at an acceptable LOS;
2. The traffic conditions in the greater network;
3. Traffic signal installation at central junctions or the alterations of existing traffic signal timing to accommodate the new traffic conditions;
4. The improved level of shop and store accessibility;
5. Access of service vehicles to the pedestrianized streets;
6. Improvement of the environment over the whole network;
7. Bus routes and changes to existing bus routes;
8. Increase in the amount of bus/public transport users due to the removal of private vehicles;
9. Environmentally friendly public transport alternatives such as minibuses;
10. The prevention of accidents due to pedestrianization;
11. The reduction of vehicle emissions in the greater area;
12. Vehicle delays at main congested junctions (reductions);
13. Reduction of vehicle energy consumption;
14. Improvement of aesthetics (no more parking and traffic intruding visuals);
15. Elimination of noise pollution caused by traffic;
16. On-street parking policy within the greater area and the construction of additional parking stations near the city centre;
17. Changes in land use, including the increase in the rent of office space and retail;
18. Pedestrian schemes work best on routes that do not directly form part of the bus network;
19. Accessibility to public transport.

Another consideration is whether the proposed area for pedestrianization forms part of an open or closed network. In an open network, community access for both pedestrians and cyclists are provided, but enables through traffic. In open networks the probability of collisions between the users of different transportation modes is more likely. In a closed network, through traffic is not promoted, making closed networks ideal for residential areas. Closed networks are however not beneficial in promoting the movement and connectivity of cyclists and pedestrians. Traffic is able to move in as many directions as possible when in an open network. Closed networks however steer traffic onto a limited number of higher order roads. Figure 25 illustrates the difference between open and closed road networks (Everitt *et al*., 2008).

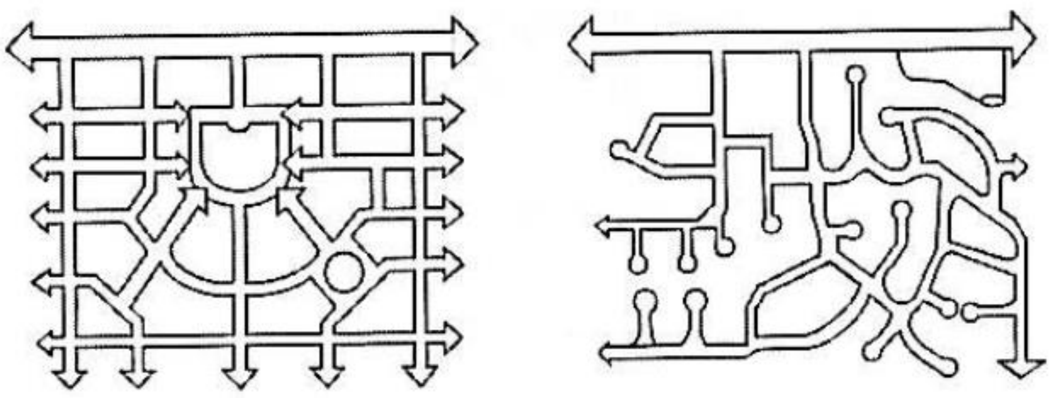

Figure 25: Open (left) versus Closed (right) networks (Everitt *et al*., 2008)

7.1.2 Pre-Feasibility Model Part 1: Suggested Checklist to Evaluate Location of Pedestrian Zone

By analysing the location characteristics from successful existing pedestrian zones, it was determined that there are characteristics that remain constant. The characteristics stated in section 7.1.1 have been used to create a suggested checklist to determine the location feasibility of a proposed pedestrian area. This suggested checklist forms the first part of the pre-feasibility model. The characteristics from existing pedestrian zones have been grouped into three parts accordingly:

Compulsory Characteristics: Include characteristics present in all of the existing pedestrian zones analysed. Since these characteristics are constant throughout all of the pedestrian zones analysed it is accepted that these characteristics play a vital role in the success of the pedestrian zone. It is therefore recommended that when the suggested checklist is filled out that all of these characteristics should be present for the proposed pedestrian area to be successful. Part 1 of the suggested checklist is thus considered to be a case of "all-or-nothing". All of the characteristics should be met. In the case where not all of the aspects are met, there should be a very good motivation as to why the pedestrian zone should still be considered.

Strongly Recommended Characteristics: Include characteristics that users of pedestrian areas deem important. Users of pedestrian areas have identified these characteristics as important for them as users to feel that the area is successful and to promote the use of these areas. The characteristics included in this part are therefore aspects that should be met once the pedestrian zone is implemented. When filling out part 2 of the suggested checklist it is suggested that most of these aspects should be met.

Recommended Characteristics: Include characteristics that should be considered. These characteristics are not solely based on evidence, but have been identified as important by some sources and can contribute in the success of a pedestrian zone. It is therefore recommended that these characteristics are met, but in the case where these characteristics are not met it will not necessarily impact the success of the pedestrian zone negatively.

Table 6 provides the suggested checklist as Part 1 of the pre-feasibility model.

Table 6: Suggested checklist as part 1 of the pre-feasibility model

	Characteristic	Description of Characteristic	Check
Compulsory Characteristic	Dense Area	Is the proposed location in a high residential and commercial area?	
	High Pedestrian Volumes	Does the location currently have high pedestrian volumes (residents, tourists, students)? Will the area be able to accommodate pedestrians with an acceptable level of services (LOS) after pedestrianization?	
	Parking	Is there space to provide alternative parking, at a reasonable price and within close proximity to the pedestrian zones, once the pedestrian zone is implemented?	
	Public Transport Access	Is there easy access to public transport from the pedestrian zone and is the pedestrian zone accessible by public transport? It should be noted that the pedestrian zone should not overlap with a bus route. In the case where the pedestrian zone will be on a bus route, will it be possible to alter the bus routes?	
	Noise Pollution	Is the location prone to noise pollution?	
	Accident Prone	Is the location prone to accidents and do accidents typically involve pedestrians?	
	Congested Area	Does the location experience heavy traffic congestion over peak and off peak time periods? It is recommended that there are alternative routes around the pedestrian area to accommodate the displaced traffic. Further considerations include whether the surrounding intersections will be able to accommodate the new traffic conditions.	
Strongly Recommended Implementations	Safety	Will the pedestrian zone be a safe environment during the day and at night time?	
	Physical Improvement	Will the area be improved in terms of aesthetics (planting of trees, adding benches, etc.) and will the physical environment be healthier (less pollution) after pedestrianization?	
	Ambience Improvements	Will the feeling of the area improve in terms of comfort, promote healthy lifestyles, create a sense of community, be relaxed and provide a space for entertainment after the implementation of pedestrianization?	
Recommendations	Access Points	The area should provide points of access for emergency and delivery vehicles into the area.	
	Not located on major routes	The proposed pedestrian zone should not be placed on major through routes.	
	Alternative Routes	Alternative traffic routes should be present and in close proximity of the pedestrian zone to accommodate the displaced traffic.	
	Compact Area	The identified area for the proposed pedestrian zone should be compact (should form a coherent shape to some extent).	
	Open Network	The proposed pedestrian zone should preferably be within an open network.	

7.2 Pre-Feasibility Model Part 2: Mathematical Model

A mathematical model is used as means to demonstrate the constituent elements and the impacts of a green pedestrian zone. In this chapter the process of mathematical modelling is elaborated upon and thereafter each step of the second part of the pre-feasibility model is discussed.

7.2.1 Mathematical Modelling

Modelling is the process in which the behaviour of objects can be described. Some methods to describe these behaviours include drawings, computer programs, physical models and most importantly, the method of interest in this study, namely mathematical formulas (Microsoft, 2018). The process of modelling in the science industry is the measurement of what is happening in the real world and is based on facts. These facts can be gathered from measurements or observations. The scientific modelling process is thus applied to analyse the obtained observations, describing the behaviour of the results that occurred and making it possible to provide predictions (Microsoft, 2018). Figure 26 illustrates the typical link between the real world and the modelled situation.

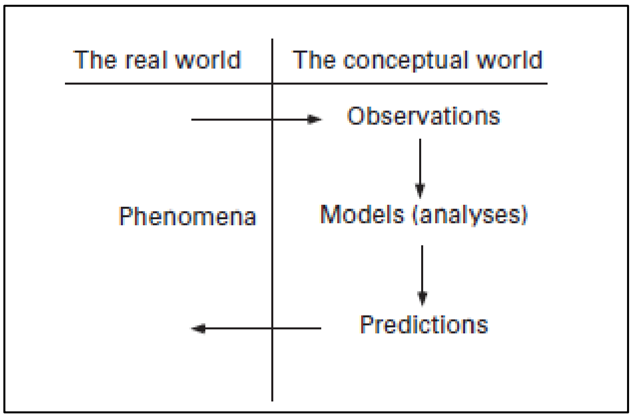

Figure 26: Link between the reality and a modelled situation (Microsoft, 2018)

Engineering modelling is applied to develop processes and systems. Engineering models should be able to analyse objects in order to predict whether the behaviour of objects are what was expected by the engineer and to predict what will happen in the future (Microsoft, 2018).

Mathematical modelling incorporates both scientific modelling and engineering modelling principles. With the use of mathematical models one set of variables can be determined from another set of variables with the application of mathematical equations. The mathematical equations are as derived from the developer of the model (National Physical Laboratory, 2018). Mathematical modelling is based on questions to determine the intention of the model. These questions are known as meta-principles and are considered philosophical in nature (Microsoft, 2018). Due to the philosophical and predictive nature of mathematical models it was deemed the best fit on which to base the pre-feasibility model of this study. The process of mathematical modelling and the corresponding meta-principle questions can be seen in Figure 27. The corresponding study specific answers to the meta-questions of the modelling process are provided in green on Figure 27.

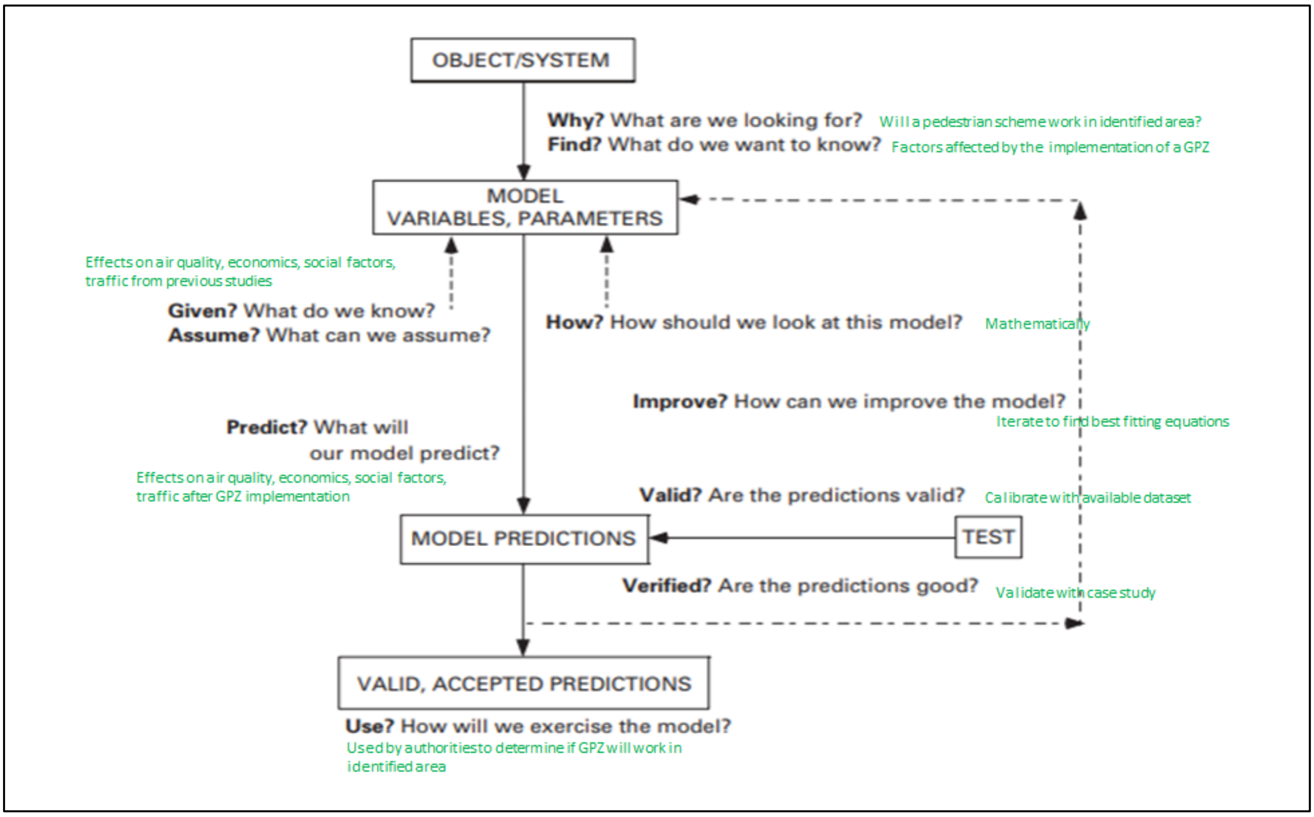

Figure 27: Meta-questions and study specific answers on them (Microsoft, 2018)

The construction of the mathematical model is an iterative process. Where the model fails in some ways, earlier stages of the model are re-examined. Assumptions, parameter values, equations and the means of calculation are adapted in order to improve and validate the model.

Mathematical modelling includes inter alia the following methods (Microsoft, 2018; National Physical Laboratory, 2018):

1. Dimensional homogeneity;
2. Abstraction and scaling;
3. Conservation and balance principles;
4. Linear models;
5. Non-linear algebraic equations;
6. Differential equations.

In addition to mathematical models, statistical models can also be applied to given datasets in order to determine the behaviour of a system, to make probabilistic predictions, to extrapolate and interpolate and to determine error estimates of the observed data (Edelstein-Keshet, 1988).

The process of modelling involves the following (National Physical Laboratory, 2018):

1. Building of the model;
2. Determining the solutions of the mathematical equations;
3. Fitting the model to data;
4. Analysis of accuracy of model;
5. Optimising the model;
6. Evaluation of uncertainties;
7. Validation of model;
8. Development of software to apply model.

It is important to note that input information is not always exact and can have associated uncertainties. The solutions obtained from the developed equations will therefore also have uncertainties which should be taken into account when assessing the quality of the outputs (National Physical Laboratory, 2018).

In this study a combination of mathematical modelling and statistics will be used to develop equations from the given datasets.

7.2.2 Pre-Feasibility Model Development

Linear modelling is used to determine the effect of green pedestrian zones on air quality. Mathematical statistics is used to determine the effect of pedestrian zones on the anticipated economic and social benefits as well as the impact of pedestrian zones on the surrounding traffic network.

The user interface of Part 2 of the pre-feasibility model is presented in Table 7. Each factor affected by the installation of a green pedestrian zone is modelled separately. The factors included are:

1. Air quality
2. Economic Impacts
3. Social Impacts
4. Traffic Impacts

} Part 2: Mathematical Model

Table 7: Final user interface of the pre-feasibility model (Part 2)

		User Input		Model Calculations		Model Output	
Air Quality	Vehicular traffic	Total Road Length of Proposed Pedestrianized Area (m)		Total Cars removed (no veh / day)		% change in PM	
				Total Road Area (m^2)		% change in HC	
		Total area of Plazas or Square if present (m^2)		Total Pedestrianized Area (m^2)		% change in NO_x	
						% change in CO	
	Green Engineering Technologies	Area of Built Up Area (m^2)				Mg additional NO_2 removed	
		Area of Green Roofs (m^2)				Mg additional O_3 removed	
						Mg additional PM_{10} removed	
		Area of Trees (m^2)				Mg additional SO_2 removed	
						% change in CO_2	
Economy		Model Output					
		Increase in turnover (%)				42.5	
		Increase in rent				YES	
		Increase in use of public transport				YES	
Social		Model Output					
		Increase in perception of good life quality (%)				48.6	
		Increase in aesthetics				YES	
		Reduction in accidents involving pedestrians				YES	
		Increase in amount of pedestrians				YES	
		Minimum expected Reduction in noise pollution due to pedestrianization (dB)				10	
		Reduction in noise pollution due to green engineering technologies				YES	
Traffic		Model Output					
		Reduction in traffic within close proximity of pedestrianized zone (%)				35	
		Impact on traffic within outer cordon				YES	
		Will traffic evaporation occur?				YES	
		Decrease in travel time				YES	
		Increase in travel speed				YES	

The model development process for each factor (air quality, economy, social and traffic) is described with the aid of the following:

1. A summary of the data obtained from previous studies;
2. A description of the mathematics used to analyse the obtained data;
3. The final mathematical equation or benefit value to be used in the pre-feasibility model;
4. A description of the functioning of the specific part of the model under consideration;
5. The required user input values for the use of the model.

7.2.2.1 Air Quality

The quality of air within the areas of pedestrian zones can be influenced immediately by the number of vehicles within the area (Chiquetto, 1997) or the installation of green engineering methods (GreenWall_Australia, 2014). Both cases are included in the model.

A numbering system is used as aid in the discussion of all the input and output elements of the model pertaining air quality. A number is allocated to each block of the model interface as presented in Table 7. Throughout the discussions in the sections to follow, each block is elaborated upon by referring to the allocated number (i.e. **BLOCK 1** or **BLOCK 7**).

The portion of the pre-feasibility model where the effects of pedestrian zones on air quality are determined is presented in Table 8. The interface with the allocated numbers is also presented in Table 8.

Table 8: Portion of pre-feasibility model to calculate the effects of pedestrian zones on air quality

		User Input		Model Calculations		Model Output	
Air Quality	Vehicular traffic	Total Road Length of Proposed Pedestrianized Area (m)	1	Total Cars removed (no veh/day)	2	% change in PM	6
				Total Road Area (m^2)	3	% change in HC	7
		Total area of Plazas or Square if present (m^2)	4	Total Pedestrianized Area (m^2)	5	% change in NO_x	8
						% change in CO	9
	Green Engineering Technologies	Area of Built Up Area (m^2)	10			Mg additional NO_2 removed	13
		Area of Green Roofs (m^2)	11			Mg additional O_3 removed	14
						Mg additional PM_{10} removed	15
		Area of Trees (m^2)	12			Mg additional SO_2 removed	16
						% change in CO_2	17

7.2.2.1.1 Effects on Air Quality due to Vehicles

In this section it is described how the information obtained from previous studies is used to determine how the amount of air pollutants within a potential pedestrian area will be influenced. Before this process is described it is important to note the following assumptions and limitations:

1. Due to a lack of previous studies providing complete before and after datasets, only a limited amount of observations are included. The lack of information can lead to mathematical equations that fit the provided datasets accurately, but are not necessarily an accurate estimation of the reality.
2. Since there are various external factors affecting the amount of air pollutants at a certain time, it is difficult to determine whether the data obtained can be compared. The seasonal effects, wind circumstances, the type of vehicles and age of vehicles present at the time of the measurements for the previous studies are therefore ignored.

Linear models, as part of the mathematical modelling process can be described as linear when the equations of the model produce responses directly proportional to the input of the equation (Microsoft, 2018). Even in the case where nonlinear models provide a better approximation of behaviour, the outcome of the model can still be linearized and the mathematics of linear systems can still be successfully applied. Linearity is applied when a system models the behaviour of a complex set of inputs. The response of a system is obtained by the sum of the individual inputs by superposing the individual responses to the individual inputs. This is known as the principle of superposition and is used by engineers to predict a response of a system with complicated inputs. The inputs into a system is thus broken down into a set of simpler inputs (Microsoft, 2018).

The statistical concept of linear regression, more specifically multiple linear regression, will be applied as a linear model to determine how the installation of a pedestrian zone will affect the amount of different air pollutants released within the identified area.

Linear regression is a predictive analysis where a set of predictor variables are examined in order to determine which of the predictor variables are significant predictors of a single outcome variable. The predictor variables are known as the independent variables and the predicted variable is known as the dependant variable. Regression therefore estimates the relationship between one dependant variable and one or more independent variables. The principle uses of regression analysis are the following (Microsoft, 2018):

1. Determining the strength of independent variables (predictors) on the dependent variable (how much change occurs in the dependent variable with a change in the independent variable);
2. Forecasting effects;
3. Determining and forecasting trends.

With the addition of independent variables to the linear regression model, the explained variance of the model will increase. The variance is typically expressed as R^2. An R^2 value of 1 indicates a perfect fit where the independent variables accurately explain the variance in the dependent variable. An R^2 value of 0 indicates no correlation between the independent and dependent variables. A good model will typically provide R^2 values between 0.3 and 0.8. Variance measures how far a set of numbers are spread out from the mean value of the dataset (Statistics Solutions, 2013).

The simplest form of a regression equation is where there is only one dependent and one independent variable, as can be seen in Equation 1 (Statistics Solutions, 2013):

$$\boldsymbol{y = \beta o + \beta n . x}$$ **Equation 1: Linear regression**

Where y = estimated dependent variable

βo = constant (function intercept)

βn = regression coefficient

x = independent variable

Multiple linear regressions which will be used in this study include a few independent variables and a single dependent variable. Multiple linear regression models are derived by using the results from statistical regression analyses of the data obtained from previous studies. A multiple linear regression model is in the form of Equation 2:

$$\boldsymbol{y = \beta o + \beta 1 . x1 + \cdots + \beta n . xn}$$ **Equation 2: Multiple linear regression**

To determine the best model for the percentage change in air pollutants, an iterative approach was followed in which different combinations of the independent variables were tested. In order to develop a regression equation, the following four possible independent variables were identified:

1. Vehicles removed;
2. Total length of road closed (m);
3. Total area of roads closed (m^2);
4. Total pedestrianized road area (m^2).

The previous studies found that cars, and more particularly busses, are responsible for the release of air pollutions (Chiquetto, 1997). It is assumed that the removal of vehicles from the street will result in reduced air pollution. Therefore, the first independent variable included in the regression modelling is:

1. ***Vehicles removed***. The total vehicles removed is obtained from previous studies. This data is presented in Table 9. In the case where this data is not available the average ratio of length of road pedestrianized to total vehicles removed is used to fill in the gaps in the data (indicated in yellow).

Table 9: Length of pedestrianized area and vehicles removed from this area

	Length of Road Pedestrianized (m)		Vehicles Removed per day	
Case Study	length (m)	Source	number of vehicles	Source
Nuremburg	5600	Measured with Google Earth	25000	(Wallztrom, 2004)
Wolverhampton	1216	Measured with Google Earth	8000	(Wallztrom, 2004)
San Jacinto	210	(Castillo-Manzano *et al.*, 2014)	15000	(Castillo-Manzano *et al.*, 2014)
Seville	520	(Castillo-Manzano *et al.*, 2014)	8920	(Castillo-Manzano *et al.*, 2014)
Kajaani	500	Measured with Google Earth	13000	(Wallztrom, 2004)
AVERAGE	1609.2	Calculated	13984	Calculated
RATIO length : total vehicle removed = 1m : 8.69cars				
Chester	1500	Measured with Google Earth	13035	Calculated with ratio =length x 8.69
Cambridge	1508	Measured with Google Earth	13104.52	
Oxford	780	Measured with Google Earth	6778.2	
Istanbul	39150	Measured with Google Earth	340213.5	
Katerini	1153	Measured with Google Earth	10019.57	
Rhodes	3920	Measured with Google Earth	34064.8	

In the pre-feasibility model the calculated ratio as in Table 10 is used. With the ratio it is assumed that 8.69 cars are removed for each 1m of road length closed. The user will therefore be required to insert the total road length in **BLOCK 1** (of the numbering system filled in on the user interface). The total cars removed in **BLOCK 2** will then be calculated with the ratio by multiplying the input road length with 8.69. Table 10 provides the numbering system for the portion of the user interface addressing the effects on air quality due to vehicles removed.

Table 10: Numbering system for user interface (air quality due to vehicles removed)

		User Input		Model Calculations		Model Output	
Air Quality	Vehicular traffic	Total Road Length of Proposed Pedestrianized Area (m)	1	Total Cars removed (no veh / day)	2	% change in PM	
				Total Road Area (m^2)	3	% change in HC	
		Total area of Plazas or Square if present (m^2)	4	Total Pedestrianized Area (m^2)	5	% change in NO_x	
						% change in CO	

It is assumed that with a larger area closed off for vehicular access, more vehicles will be removed from the overall network, resulting in an anticipated further reduction in air pollution. Therefore, the independent variables identified to model this second assumption are:

2. ***Total length of road closed (m)***, with the length of roads obtained from previous studies and Google Earth measurements.
3. ***Total area of roads closed (m^2)***, determined as road length times the road width. The road width is assumed to be 3m due to the majority of the previous studies having narrow one-way streets in the old town. This was determined as an average measurement between the different road widths of the case studies included in the previous studies and Google Earth measurements. The model calculation of **BLOCK 3** is therefore equal to total road length multiplied by 3m.
4. and ***total pedestrianized road area (m^2)***, determined as the sum of the area of plazas (as obtained from previous studies and Google Earth measurements) and the *total area of roads closed*. **BLOCK 4** is therefore specified as an input value by the user in the case where there will be additional areas such as plazas also pedestrianized and not only road segments. The total pedestrianized area of **BLOCK 5** will therefore be the sum of the *total area of plazas* (input value) in BLOCK 4 and the calculated *total road area* of BLOCK 3.

The air pollutants included in this model are particulate matter (PM), nitrogen oxides (NO_x), hydrocarbons (HC) and carbon monoxide (CO). The dependent variable in the regression modelling process is the amount of air pollution. Each air pollutant is modelled separately with the independent variables as listed above. It is an iterative process to determine the best equation to fit the datasets for the different air pollutants, where different combinations of independent variables are included to ultimately determine the best fitting equation resulting in the most accurately calibrated model.

The multiple linear regression models and equations for each air pollutant are developed as follows:

Particulate Matter (PM):

The input values to determine the equation for PM is presented in Table 11.

Table 11: Input data for linear regression model of PM

	X					Y	*Calibration*
CASE STUDY	***TOTAL CARS REMOVED (daily)***	***TOTAL ROAD LENGTH (m)***	***TOTAL PED AREA (m2)***	***TOTAL ROAD AREA (l x b) (m2)***	***CLOSED AREA (PLAZAS) (m2)***	***% change in PM***	***output***
Chester	13035	1500	4500	4500	0	5.75	7.89
Nuremburg	25000	5600	49616	16800	32816	-16.9	-16.90
Cambridge	13105	1508	4524	4524	0	-5	-10.41
Oxford	6779	780	2340	2340	0	-25	-21.79
Istanbul	340214	39150	117450	117450	0	-52.83	-52.77

The output values obtained from the statistical regression data analysis in MS Excel are as obtained in Table 12:

Table 12: Regression statistics and linear regression model outcomes for PM

Regression Statistics	
Multiple R	0.988877263
R Square	0.977878241
Adjusted R Square	-0.088487035
Standard Error	6.640318266
Observations	5

	Coefficients	*Standard Error*	*t Stat*
Intercept	9.547140371	6.359960431	1.501132039
TOTAL CARS REMOVED (daily)	-38.09979334	11.64359636	-3.272167136
TOTAL ROAD LENGTH (m)	0	0	65535
TOTAL PED AREA (m2)	-27.47482229	8.396487839	-3.272180323
TOTAL ROAD AREA (l x b) (m2)	137.8368553	42.12411183	3.272160511

The coefficient of determination, R^2, is the proportion of the variance in the dependent variable that can be predicted and explained from the independent variables. From the regression statistics it can be seen that a R^2 value of 0.98 is obtained. This indicates that the model explains 98% of the variability of the response data around its mean.

The t-stat value is obtained by dividing the coefficients with its standard error. The t-stat therefore aids in measuring the precision with which the regression coefficients are measured. The t-stat values for all of the independent variables, including the equation intercept, fall within a 15% error margin or confidence interval of 85% (t-stat values > 1.44). The absolute value of the t-stat values are taken when compared to the confidence interval (z value) of the error margin.

Equation 3 is derived from this regression as follows:

$$\%\ change\ in\ PM = 9.547 - 38.1(total\ cars\ removed) + 0(total\ road\ length) - 27.47(total\ pedestrianized\ area) + 137.84(total\ road\ area)$$

Equation 3: Percentage change in PM due to vehicle removal

The coefficients for the equation above are obtained from the regression model. This equation is applied to the dataset in order to calibrate the model. The percentage change in PM, as determined with the application of the derived equation, is presented in the output column of Table 11: Input data for linear regression model of PMIt can be seen that the output values are of the same order as the values obtained from previous studies, thus indicating that the derived equation is a good fit and accurately represents the dataset. **BLOCK 6** of the master pre-feasibility model will therefore be equal to the developed linear regression equation.

<table>
<tr><td rowspan="5">Air Quality</td><td colspan="3">User Input</td><td colspan="2">Model Calculations</td><td colspan="2">Model Output</td></tr>
<tr><td rowspan="4">Vehicular traffic</td><td rowspan="2">Total Road Length of Proposed Pedestrianized Area (m)</td><td rowspan="2"></td><td>Total Cars removed (no veh / day)</td><td></td><td>% change in PM</td><td>6</td></tr>
<tr><td>Total Road Area (m^2)</td><td></td><td>% change in HC</td><td></td></tr>
<tr><td rowspan="2">Total area of Plazas or Square if present (m^2)</td><td rowspan="2"></td><td rowspan="2">Total Pedestrianized Area (m^2)</td><td rowspan="2"></td><td>% change in NO_x</td><td></td></tr>
<tr><td>% change in CO</td><td></td></tr>
</table>

From the results it can however be seen that the independent variable of ***total road length*** produces a coefficient equal to zero. This indicates that this variable does not have an influence on the dependent variable of percentage change in PM. According to the correlation calculation done between the independent variables, as presented in Table 13, it can however be seen that there is a strong correlation between the other independent variables and the ***total road length***, with correlation values approximately equal to 1, indicating a strong linear relationship between the independent variables.

Table 13: Correlation between input variables of linear regression model

	TOTAL CARS REMOVED (daily)	*TOTAL ROAD LENGTH (m)*	*TOTAL PED AREA (m2)*	*TOTAL ROAD AREA (l x b) (m2)*
TOTAL CARS REMOVED (daily)	1	0.997413661	0.933095608	0.997413661
TOTAL ROAD LENGTH (m)	0.997413661	1	0.956530531	1
TOTAL PED AREA (m2)	0.933095608	0.956530531	1	0.956530531
TOTAL ROAD AREA (l x b) (m2)	0.997413661	1	0.956530531	1

A second regression was conducted where the ***total road length*** as independent variable was removed. The regression statistics for this model estimation is provided in Table 14. It can be concluded that the obtained R^2 value of 0.74, for this model is deemed acceptable. The t-stat values however indicate an error margin of larger than 30%, which is unacceptable. The independent variables do therefore not accurately explain the variation in the dependent variable. Furthermore, it is also noted that the coefficients obtained for the regression equation is very small, again indicating that the independent variables do not have a significant impact on the dependent variable. The independent variable ***total cars removed*** produce a coefficient equal to zero. This can be attributed to the removal of the independent variable ***total road length*** from this regression.

Table 14: Regression statistics and linear regression model outcomes for PM, second iteration

Regression Statistics	
Multiple R	0.860825074
R Square	0.741019809
Adjusted R Square	0.482039618
Standard Error	16.06561462
Observations	5

	Coefficients	*Standard Error*	*t Stat*
Intercept	-6.717819283	9.599067563	-0.699840817
TOTAL CARS REMOVED (daily)	0	0	65535
TOTAL PED AREA (m2)	-0.000166354	0.000448187	-0.371169659
TOTAL ROAD AREA (l x b) (m2)	-2.57104E-05	5.10586E-05	-0.503545974

From the two regression models tested to determine the percentage change in PM it can be concluded that the first model is the more accurate model and will therefore be used in the pre-feasibility model.

<u>Hydrocarbons (HC):</u>

The input values to determine the equation for Hydrocarbons (HC) is presented in Table 15.

Table 15: Input data for linear regression model of HC

	X					Y	*Calibration*
CASE STUDY	***TOTAL CARS REMOVED (daily)***	***TOTAL PED AREA (m2)***	***TOTAL ROAD LENGTH (m)***	***TOTAL ROAD AREA (l x b) (m2)***	***CLOSED AREA (PLAZAS) (m2)***	***% change in HC***	***output***
Chester	13035	4500	1500	4500	0	-6	-6.00
Katerini	10020	3459	1153	3459	0	-25	-25.00
Rhodes	34065	11760	3920	11760	0	-32.3	-32.30

A requirement in conducting a linear regression is for the total of independent variables included in the regression model to be equal to one less than the total observations. Therefore, only the ***total cars removed*** and the ***total pedestrianized area*** were used as independent variables for the case of HC. The output values obtained from the statistical regression data analysis in MS Excel are as presented in Table 16.

Table 16: Regression statistics and linear regression model outcomes for HC

Regression Statistics	
Multiple R	1
R Square	1
Adjusted R Square	65535
Standard Error	0
Observations	3

	Coefficients	*Standard Error*	*t Stat*
Intercept	4.147297297	0	65535
TOTAL CARS REMOVED (daily)	-49.64513513	0	65535
TOTAL PED AREA (m2)	143.8031532	0	65535

From the results it can be seen that a perfect fit is obtained, noting R^2 to be equal to 1 and the independent variables exactly describing the variance in the percentage change in HC within a pedestrianized area. It should however be taken into consideration that due to only three observations included in the model it may not be a true representation of reality. Increasing the number of observations will most likely change the regression results. This should be taken into consideration when the results of this model are interpreted. Equation 4, as obtained from the regression is as follows:

$$\%\ change\ in\ HC = 4.15 - 49.65(total\ cars\ removed) + 143.80(total\ pedestrianized\ area)$$

Equation 4: Percentage change in HC due to vehicle removal

Applying the regression model results in exactly the same actual percentage change in HC, as can be seen in the output column of Table 15. The equation can therefore be considered to be calibrated. Within the pre-feasibility model, **BLOCK 7** will be determined with the application of this equation.

<table>
<tr><td rowspan="5">Air Quality</td><td colspan="3">User Input</td><td colspan="2">Model Calculations</td><td colspan="2">Model Output</td></tr>
<tr><td rowspan="4">Vehicular traffic</td><td rowspan="2">Total Road Length of Proposed Pedestrianized Area (m)</td><td rowspan="2"></td><td>Total Cars removed (no veh / day)</td><td></td><td>% change in PM</td><td></td></tr>
<tr><td>Total Road Area (m^2)</td><td></td><td>% change in HC</td><td>7</td></tr>
<tr><td rowspan="2">Total area of Plazas or Square if present (m^2)</td><td rowspan="2"></td><td rowspan="2">Total Pedestrianized Area (m^2)</td><td rowspan="2"></td><td>% change in NO_x</td><td></td></tr>
<tr><td>% change in CO</td><td></td></tr>
</table>

Nitrogen Oxides NO_x:

The input values to determine the equation for Nitrogen Oxides (NO_x) are presented in Table 17.

Table 17: Input data for linear regression model of NO_x

	X					Y	Calibration
Case Study	***TOTAL CARS REMOVED (daily)***	***TOTAL ROAD LENGTH (m)***	***TOTAL PED AREA (m2)***	***TOTAL ROAD AREA (l x b) (m2)***	***CLOSED AREA (PLAZAS) (m2)***	***% change in NO_x***	***output***
Chester	13035	1500	4500	4500	0	-0.5	-0.50
Nuremburg	25000	5600	49616	16800	32816	-35.3	-35.30
Katerini	10020	1153	3459	3459	0	-35	-35.00
Rhodes	34065	3920	11760	11760	0	-45.6	-45.60

As previously stated, a requirement in conducting a linear regression is for the total of independent variables included in the regression model to be equal to one less than the total observations. Therefore, only the ***total cars removed***, the ***total road length*** and the ***total pedestrianized area*** were used as independent variables for the case of NO_x. The output values obtained from the statistical regression data analysis in MS Excel are presented in Table 18.

Table 18: Regression statistics and linear regression model outcomes for NO_x

Regression Statistics	
Multiple R	1
R Square	1
Adjusted R Square	65535
Standard Error	0
Observations	4

	Coefficients	*Standard Error*	*t Stat*
Intercept	16.38243243	0	65535
TOTAL CARS REMOVED (daily)	-89.31504504	0	65535
TOTAL ROAD LENGTH (m)	969.3538086	0	65535
TOTAL PED AREA (m2)	-64.40577403	0	65535

Similar to the results obtained for HC, a perfect fit is obtained for the case of NO_x. This can be noted from R^2 being equal to 1, again indicating that the independent variables to be exactly describing the variance in the percentage change in NO_x within a pedestrianized area. It should however be taken into consideration that due to only three observations included in the model it may not be a true representation of reality and additional observations will most likely change the regression results. This should be considered when the results of this model are interpreted.

Equation 5 obtained from the regression is as follows:

$$\% \, change \, in \, NOx = 16.38 - 89.32(total \, cars \, removed) + 969.35(total \, road \, length) - 64.41(total \, pedestrianized \, area)$$

Equation 5: Percentage change in NO_x due to vehicle removal

The output obtained from the regression equation as applied for NO_x, is exactly the same as obtained from previous studies and therefore the model is regarded as calibrated as seen in Table 17. Equation 5 is used in Part 2 of the pre-feasibility model to calculate the value of **BLOCK 8**.

	User Input			Model Calculations		Model Output	
Air Quality	Vehicular traffic	Total Road Length of Proposed Pedestrianized Area (m)		Total Cars removed (no veh / day)		% change in PM	
				Total Road Area (m^2)		% change in HC	
		Total area of Plazas or Square if present (m^2)		Total Pedestrianized Area (m^2)		% change in NO_x	8
						% change in CO	

Carbon Monoxide (CO):

The last air pollutant included in the study is Carbon Monoxide (CO). The available data on CO as obtained from previous studies is presented in Table 19:

Table 19: Input data for linear regression model of CO

	X					Y	*Calibration*
Case Study	*TOTAL CARS REMOVED (daily)*	*TOTAL ROAD LENGTH (m)*	*TOTAL PED AREA (m2)*	*TOTAL ROAD AREA (l x b) (m2)*	*CLOSED AREA (PLAZAS) (m2)*	*% change in CO*	*output*
Chester	13035	1500	4500	4500	0	-6.5	1.51
Nuremburg	25000	5600	49616	16800	32816	-12.4	-12.40
Oxford	6779	780	2340	2340	0	-75	-65.52
Katerini	10020	1153	3459	3459	0	-17.2	-34.96
Rhodes	34065	3920	11760	11760	0	-43.8	-43.53

The regression statistics are as determined in Table 20:

Table 20: Regression statistics and linear regression model outcomes for CO

Regression Statistics	
Multiple R	0.924660781
R Square	0.85499756
Adjusted R Square	-0.580009759
Standard Error	21.66330207
Observations	5

	Coefficients	*Standard Error*	*t Stat*
Intercept	17.82107092	31.1195343	0.57266509
TOTAL CARS REMOVED (daily)	-93.57759833	41.95305984	-2.230530948
TOTAL ROAD LENGTH (m)	0	0	65535
TOTAL PED AREA (m2)	-67.47896162	30.25271997	-2.230508916
TOTAL ROAD AREA (l x b) (m2)	338.5384462	151.775071	2.230527346

From the regression statistics it can be seen that a R^2 value of 0.85 is obtained. This indicates that the model predicts 85% of the variability of the response data around its mean. The t-stat values for all of the independent variables, including the equation intercept, falls within a 15% error margin or confidence interval of 85% (t-stat values > 1.44), except that of the intercept.

Equation 6 derived from this regression is as follows:

$$\%\ change\ in\ CO = 17.82 - 93.58(total\ cars\ removed) + 0(total\ road\ length) - 67.47(total\ pedestrianized\ area) + 338.54(total\ road\ area)$$

Equation 6: Percentage change in CO due to vehicle removal

The coefficients for the equation above are obtained from the regression model. This equation is applied to the dataset in order to calibrate the model. The percentage change in CO as obtained with the derived equation is indicated in the output column of Table 19. It can be seen that the output values are comparable with the values obtained from previous studies, thus indicating the derived equation to be closely calibrated with the initial dataset.

Similarly to the case for PM, it can be seen that the independent variable of ***total road length*** results in a coefficient equal to zero. This is an indication that this variable does not have an influence on the dependent variable of percentage change in CO. Due to the strong correlation between the other independent variables and the ***total road length*** it was however decided not to remove this variable from the regression analysis.

The value of **BLOCK 9** in the pre-feasibility model is determined with the above developed equation.

		User Input		Model Calculations		Model Output	
Air Quality	Vehicular traffic	Total Road Length of Proposed Pedestrianized Area (m)		Total Cars removed (no veh / day)		% change in PM	
				Total Road Area (m^2)		% change in HC	
		Total area of Plazas or Square if present (m^2)		Total Pedestrianized Area (m^2)		% change in NO_x	
						% change in CO	9

7.2.2.1.2 Effects on Air Quality due to Green Engineering Technologies

The data obtained from the literature review and previous studies were analysed. The studies included the effects of green engineering technologies (green walls, green roofs and trees) on air quality and how these green engineering technologies contribute to the removal of air pollutants. The data obtained from the case study in Toronto is processed in order to obtain the reduction in air pollutants for every square metre of green engineering technologies implemented (Currie & Bass, 2008). The case study conducted on Hong Kong indicates that an area of green roofs equal to 218.3m^2 resulted in an overall decrease of 1.85% in CO_2 (13.8g of CO_2 removed per minute) (Li *et al.*, 2010). It can therefore be assumed that for 1m^2 of green roofs, a reduction of 1.85% in CO_2 can also be expected, since the ratio of green roof area to grams of CO_2 removed will remain constant.

Table 21 provides a summary of the increase in removed air pollutants (therefore the additional mass of the pollutant removed by the introduction of a green engineering technology to the area).

Table 21: Removal of air pollutants due to green engineering technologies

Mg additional pollutant removed				Source
Pollutant	Green walls (per 1m^2 of built up area)	Green roofs per 1m^2	Trees per 1m^2	
NO_2	0.0048	0.06	0.04	(Currie & Bass, 2008)
O_3	0.0084	0.12	0.09	
PM_{10}	0.0105	0.08	0.02	
SO_2	0.0018	0.02	0.02	
% reduction in pollutant				
CO_2	No data	1.85	No data	(Li *et al.*, 2010).

There are however multiple external factors that may have a significant influence on how pollutants are absorbed by the various green engineering technologies. The air pollutant removal for green engineering technologies should be treated as an approximation. Since the pre-feasibility model is used for only roughly determining whether the implementation of a green pedestrian zone with some green engineering technologies would be feasible, it is assumed that these external factors should not affect the implementation thereof. The results obtained in the pre-feasibility model will be used only to determine whether the proposed pedestrian zone will have a positive effect on the air quality or not.

Generally, the following factors affecting the absorption of air pollutants should be taken into consideration in the case where new measurements are taken. These factors were however not considered in developing the pre-feasibility model (Currie & Bass, 2008) (GreenWall_Australia, 2014) (Yang *et al.*, 2008) (Li et al., 2010):

1. The orientation of the green walls/roofs;
2. Existing urban vegetation;
3. Vegetation on the green walls/roofs;
4. Types of trees;
5. Transpiration rates for different plant leave types;
6. Measures/methods how the changes in pollution is captured;
7. Wind speeds;
8. Seasons;
9. Type of city (city conditions) and climates of different cities;
10. The initial concentration of air pollutants;
11. Times of day when measurements were taken.

The following aspects are also influenced by green engineering technologies. These factors do however not have immediate impacts on the users of the pedestrian zone. These factors are therefore excluded from the study:

1. energy consumption of buildings;
2. energy consumption for air-conditioning in the case where the heat is discharged at pedestrian level;
3. economic analysis associated with the removal of pollutants;
4. urban run-off;
5. urban heat island effect.

Within Part 2 of the pre-feasibility model, the user of the model will be required to provide the area of built up area to determine the effect of green walls, area of green roofs and area of trees to be planted. This input data will form the values for **BLOCKS 10, 11 and 12.**

	User Input				Model Output	
Air Quality	Green Engineering Technologies	Area of Built Up Area (m^2)	10		Mg additional NO_2 removed	13
		Area of Green Roofs (m^2)	11		Mg additional O_3 removed	14
					Mg additional PM_{10} removed	15
		Area of Trees (m^2)	12		Mg additional SO_2 removed	16
					% change in CO_2	17

The equations to determine the percentage change in air pollutants of the model output column will be based on the values obtained from previous studies as presented in Table 21. The set of equations (Equation 7) will be the following:

BLOCK 13: Mg change in NO_2

= 0.0048(input built up area) + 0.06 (input green roof area) + 0.04 (input area of trees);

BLOCK 14: Mg change in O_3

= 0.0084(input built up area) + 0.12 (input green roof area) + 0.09 (input area of trees);

BLOCK 15: Mg change in PM_{10}

= 0.0105 (input built up area) + 0.08 (input green roof area) + 0.02 (input area of trees);

BLOCK 16: Mg change in SO_2

= 0.0018 (input built up area) + 0.02 (input green roof area) + 0.02 (input area of trees);

BLOCK 17: % change in CO_2 = 1.85% reduction.

Equation 7: Set of equations to determine removal of air pollutants due to green engineering technologies

7.2.2.2 Economic Impacts

The data obtained from previous studies was analysed in order to determine whether there is a relationship between pedestrianizing an area and the economic impacts thereof. The data from previous studies is summarized in Table 22. It can be seen that the dataset is not very complete except for the percentage increase in turnover due to pedestrianization. It was therefore decided that the average increase in turnover, calculated as 42.5%, would be used as a constant in the pre-feasibility model. The percentage increase in turnover for all of the case studies is of a similar order of magnitude therefore it is assumed that the average of these values is acceptable. The other economic factors affected by pedestrianization have too little data available to determine specific trends. These factors will still be included in the model, but as a “YES” value and not as a numerical value. The value for these factors can however change in the case where more data is obtained. It will then be recommended to make use of a weighted average in order to determine the combined economic benefits and therefore incorporating all of the factors listed in Table 22.

With the measuring of economic impacts due to pedestrianization, only the immediate impacts were assessed. These factors are considered to be the percentage increase in pedestrians directly associated with the increase in retail turnover. It is assumed that with an increase in the amount of pedestrians walking past the retail facilities within a pedestrianized zone the turnover will increase. It is assumed that the measured increase in turnover includes both sales and restaurant and café turnover.

There are other economic aspects to consider when implementing a pedestrian zone. These factors do not necessarily have an immediate effect and are therefore omitted in the scope of this study. This includes factors such as, but are not limited to, the following:

1. Increase in property value;
2. Increase in rent of properties and gross leasable area;
3. Effect on the Gross Domestic Profit (health improvements due to less air pollution, reduction of urban heat island effect);
4. Encroaching (where restaurants extend to the outside and take up sidewalk space);
5. Tourism (where retail is not involved);
6. Less accidents involving pedestrians;
7. Growth in the use of public transport.

Table 22: Summary of economic impacts due pedestrianization in previous studies

Case Study	Increase in pedestrians (%) increase in feet	Positive effect on business (%) increase in turnover	m^2 of pedestrian zone	% increase in rent	increase in PT use %	source
Oxford	8.5	-	2340	-	9	(Wallztrom, 2004)
Istanbul	-	51	117450	-	-	(Öztaş & Akı, 2014)
Austria	-	60	-	-	-	(Soni & Soni, 2016)
Scandinavia	-	60	-	-	-	(Soni & Soni, 2016)
Germany	-	60	-	-	-	(Soni & Soni, 2016)
Hans-Klaus	30	17	-	22	-	(Whitehead *et al.*, 2006)
Köln	-	(30-40) 35	-	-	-	(Hass-Klau, 1993b)
Essen	-	(15–35) 25	-	-	-	(Hass-Klau, 1993b)
Seville	33.5	51	-	-	-	(Castillo-Manzano *et al.*, 2014)
Mannheim	-	16	-	-	-	(Hass-Klau, 1993b)
München	-	40	-	-	-	(Hass-Klau, 1993b)
Kajaani	-	52	3126	-	-	(Wallztrom, 2004)
Wolverhampton	-	-	3647	-	30	(Wallztrom, 2004)
Ghent	-	-	17779	-	4	(Wallztrom, 2004)
AVERAGE		42.5				

The user interface of the portion of the pre-feasibility model addressing the economic impacts is presented in Table 23:

Table 23: Portion of pre-feasibility model to calculate the effects of pedestrian zones on economic factors

Economy	Model Output	
	Increase in turnover (%)	42.5
	Increase in rent	YES
	Increase in use of public transport	YES

In conclusion, the pre-feasibility model for the economic benefits will provide a predetermined set of outputs. The outputs will therefore be an estimation based on the results of the previous studies and therefore no input will be required. The estimated benefits of pedestrianization on the immediate economy will be:

1. 42.5% increase in turnover (average of previous studies);
2. Increase in rent;
3. Increase in the use of public transport.

Some limitations and uncertainties associated with the data which are considered to be negligible include factors such as:

1. Time period after which the increase in turnover is measured;
2. It is assumed that the measurements were taken as an average value and not measured over a time period where retail will generally increase such as Christmas time or peak tourist seasons.

7.2.2.3 Social Impacts

The same approach as with the economic impacts was followed in determining the impact of pedestrian zones on social aspects. The data obtained from previous studies were analysed in order to determine whether there is a relationship between pedestrianizing an area and the social benefits for the residents and users of the area. The data from these previous studies is summarized in Table 24. Again, the dataset is not comprehensive, except for the percentage increase in the perception of a good quality of life.

By considering the results on the percentage increase in the perception of good life quality it is noticeable that it ranges from very high (90%) to very low (4.5%). The initial thought was to eliminate the outliers from the dataset by means of the interquartile range. The dataset is however too small to accurately use this method to eliminate outliers. It is further assumed that the results obtained are correct and not that of measurement or recording errors. Therefore it was decided to keep the outliers in the dataset in order to take into account that these outliers may be of importance.

A second approach was taken in order to identify possible trends in how the perception of quality of life is influenced by pedestrianization by determining if there are any noticeable trends in the average ratio of pedestrianized area to percentage increase in perception of good life quality. It was anticipated that with an increase in total pedestrianized area, the perception of the quality of life would be higher. This was however not the case and no correlation between the ratio of the pedestrianized area and the perception of good life quality (%) could be determined.

As a final approach it was decided to use the average of the perception of good quality of life and thus accommodating all outliers. The other social factors affected by pedestrianization have too little data available to determine specific trends.

Table 24: Summary of social impacts due pedestrianization in previous studies

Case Study	Feeling of residents	Increase in perception of good life quality (%)	m2 of pedestrian zone	Ratio ped area: % perception increase	% improvement in aesthetics	Reduction in accident levels (%)	% increase in pedestrians	source
Cambridge	good/safer							(Wallztrom, 2004)
Kajaani		20	3126	1:156	8			(Wallztrom, 2004)
Ghent	good/events/ revitalized culture					30		(Wallztrom, 2004)
Seoul		4.5	-				9	(Jung *et al.*, 2017)
Seville	Livelier atmosphere	90	1560	1:17				(Castillo-Manzano *et al.*, 2014)
Istanbul		80	117450	1:1468	58			(Öztaş & Akı, 2014)
Katerini						44		(Brebbia, 2000)
AVERAGE		48.6						

Previous studies indicate that pedestrianization can lead to the reduction in noise pollution (Chiquetto, 1997). The reduction in noise pollution is considered a social benefit since it affects the quality of life. Table 25 provides a summary of the effects of pedestrian schemes on noise pollution as obtained from previous studies. From the results it is difficult to determine a specific trend associated with the amount of noise pollution after the implementation of a pedestrian scheme.

Table 25: Summary of impacts on noise pollution due pedestrianization in previous studies

Case	Reduction in Noise Pollution	Source
922 m^2 of Green Walls	4.3 dB	(Veisten *et al.*, 2012)
India	15-20 dB	(Soni & Soni, 2016)
Leeds	10 dB	(Chiquetto, 1997).
Chester	50%	(Chiquetto, 1997).

In conclusion, the pre-feasibility model associated with social benefits will again provide a predetermined set of outputs. The portion of the pre-feasibility model addressing the social impacts is presented in Table 26.

Table 26: Portion of pre-feasibility model to calculate effects of pedestrian zones on social factors

	Model Output	
Social	Increase in perception of good life quality (%)	48.6
	Increase in aesthetics	YES
	Reduction in accidents involving pedestrians	YES
	Increase in amount of pedestrians	YES
	Minimum expected reduction in noise pollution due to pedestrianization (dB)	10
	Reduction in noise pollution due to green engineering technologies	YES

The outputs are therefore an estimation based on the results of the previous studies and therefore no input will be required. The estimated benefits of pedestrianization on the immediate social environment for the pre-feasibility model are therefore:

1. 48.6% increase in the perception of a good quality of life (average of previous studies);
2. Increase in aesthetics;
3. Reduction in accidents involving pedestrians;
4. Increase in the amount of pedestrians;
5. A reduction of at least 10dB in noise pollution (due to pedestrianization);
6. Reduction in noise pollution due to green engineering technologies.

It is assumed that the perception of a good quality of life includes the following factors:

1. Health benefits;
2. Feeling of community;
3. Feeling of safety;
4. Feeling of nature;
5. Increase in the activity levels of individuals;
6. Decrease in levels of depression;
7. Livelier atmosphere in the area.

7.2.2.4 Impacts on Traffic of Surrounding Network

Considering previous studies it was found that traffic evaporation took place in all of the cases. Table 27 provides a summary of the results obtained from previous studies.

Table 27: Summary of impacts on the surrounding traffic network due pedestrianization in previous studies

Case Study	Presence of Traffic Evaporation	% decrease in travel time	% increase in travel speed	% reduction in traffic within close proximity of GPZ	% change in traffic within the larger road network	source
Chester	Yes	2.8	3.1	-	-	(Chiquetto, 1997).
Kajaani	Yes	-	-	-	No increase	(Wallztrom, 2004)
Wolverhampton	Yes	-	-	14	1 decrease	
Nuremburg	Yes	-	-	25	19 increase	
Cambridge	Yes	-	-	80	No increase	
Oxford	Yes	-	-	20	1.13 decrease	
AVERAGE				35		

From the results it is possible to determine the average percentage reduction in traffic within close proximity of the pedestrianized zone (inner cordon). As with the economic and social benefits, it is not possible to identify other trends in the effects of pedestrianization on the traffic conditions within the area due to a lack of data. The output provided in the pre-feasibility model will therefore also be predetermined based on the previous studies and require no input values from the user. The portion of the pre-feasibility model for traffic impacts is presented in Table 28.

Table 28: Portion of pre-feasibility model to calculate the effects of pedestrian zones on the surrounding traffic network

	Model Output	
Traffic	Reduction in traffic within close proximity of pedestrianized zone (%)	35
	Impact on traffic within outer cordon	YES
	Will traffic evaporation occur?	YES
	Decrease in travel time	YES
	Increase in travel speed	YES

It can be concluded that the output set will include the following anticipated benefits:

1. 35% reduction in traffic within close proximity of the pedestrianized zone;
2. Very little to no impact on traffic conditions further away from the pedestrianized zone (outer cordon);
3. Traffic evaporation WILL occur;
4. Decrease in travel time;
5. Increase in travel speed.

Some limitations and uncertainties to consider when the results are interpreted include factors such as, but are not limited to:

1. The time when the data was recorded and whether the data was obtained during peak hours when demand was at the highest;
2. The total travel distances of each trip of the network users.

8. CASE STUDY: STELLENBOSCH

In this chapter a practical application of the pre-feasibility model is conducted. The mid-town of Stellenbosch serves as suggested case study for an area that could be redesigned as a green pedestrian zone. The pre-feasibility model developed in Chapter 7 is applied to the area as identified in Figure 28. The proposed green pedestrian zone includes a section of Church, Andringa and Ryneveld Streets.

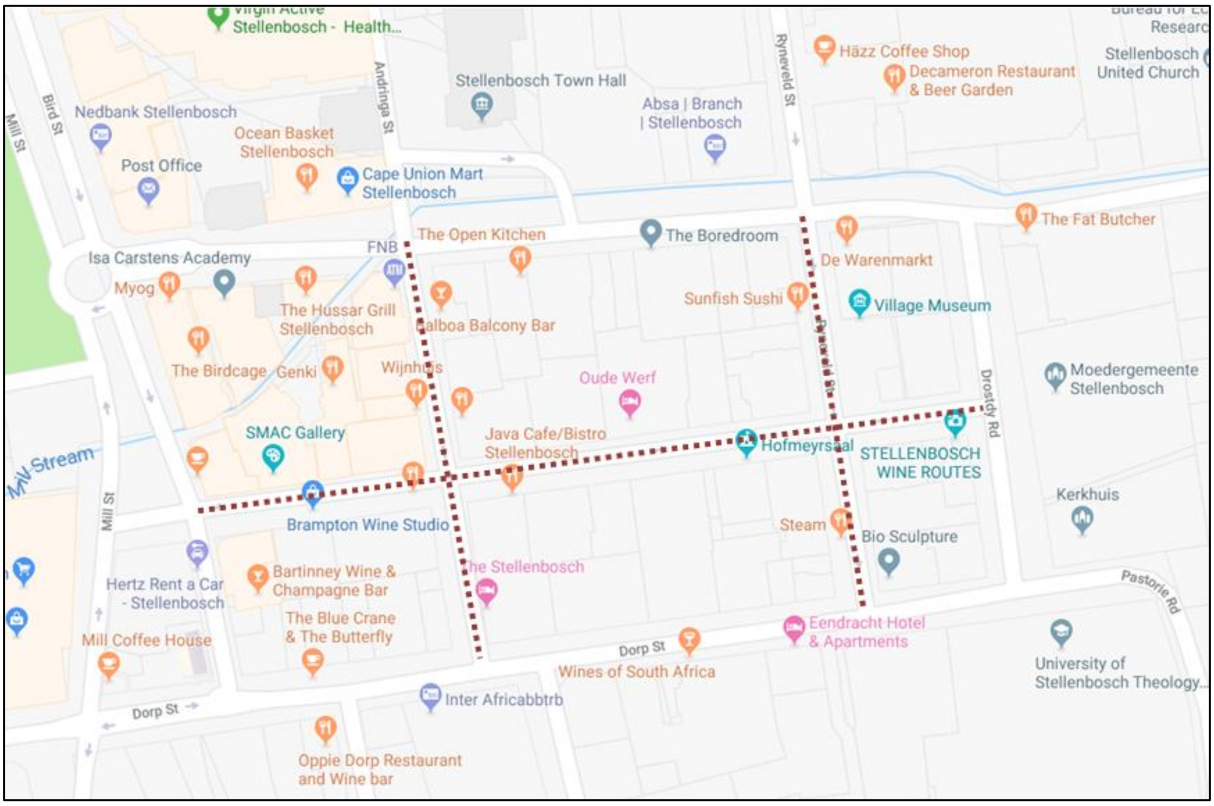

Figure 28: Proposed pedestrian streets for the Stellenbosch case study

8.1 Description of Stellenbosch Mid-Town

The town of Stellenbosch has history dating back to 1679. Due to its heritage, Victorian architecture, university and location within the Cape Winelands, the town is very popular. Stellenbosch features as one of the top tourist, educational and business destinations in South Africa. Associated with the popularity of the town is the large number of tourists, residents and students in the town (Stellenbosch Wine Route, 2018). These factors all contribute to the large number of pedestrians in the town.

From observations, one of the main retail and restaurant attraction points of the town is identified as the area between the streets as presented in Figure 28. Currently these streets operate as one-way streets. Parking within this area is also problematic. There is not enough parking to accommodate the volume of potential visitors driving to the area. Another observation made for this area is the absence of public transport.

Figure 29 provides a view of Church Street, Figure 30 a view of Andringa Street and Figure 31 a view of Ryneveld Street to illustrate the look and the feel of the central area of Stellenbosch town.

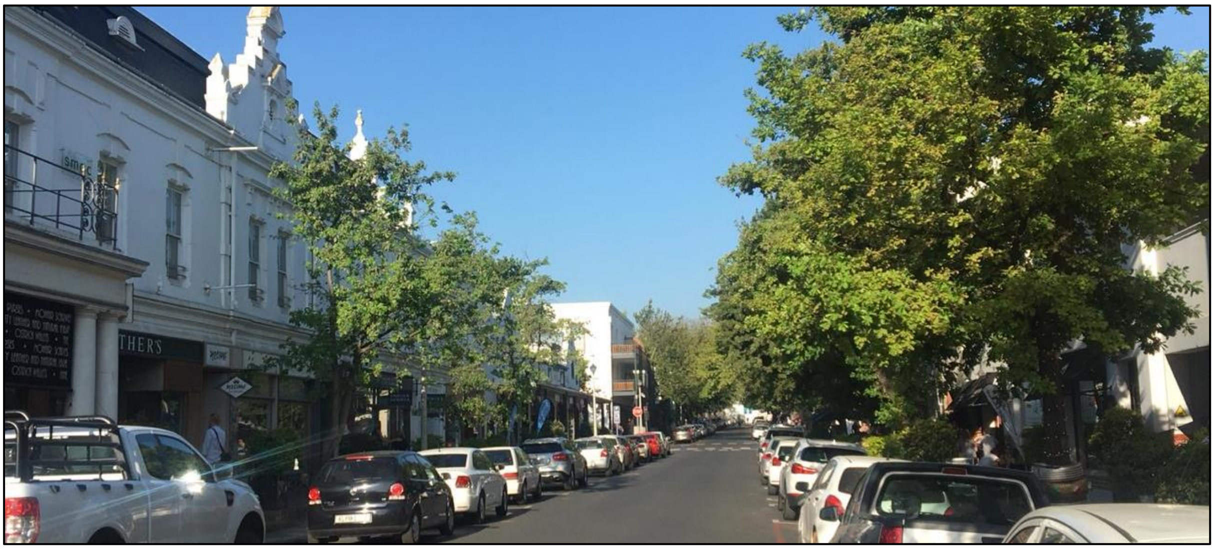

Figure 29: View of Church Street in Stellenbosch town centre (Photo: A Maritz)

Figure 30: View of Andringa Street in Stellenbosch town centre (Photo: A Maritz)

Figure 31: View of Ryneveld Street in Stellenbosch town centre (Photo: A Maritz)

8.2 Why Stellenbosch as Case Study

From discussions with Mr Sani, the owner of Wijnhuis restaurant in Ryneveld Street, and Mr Pelser, the chairman of the Stellenbosch Rate and Tax Payers Association, it can be derived that the current debate in the historic town of Stellenbosch is about the retention of the rural character of the town versus urban development. Vineyards and other farmland within the municipal boundaries are replaced by business park developments, hospitals and residential areas. In addition, plans for road development in the area are of great concern to residents.

The University of Stellenbosch is also driving an expansion programme resulting in additional needs for student housing in the town. The expansion programme is also the cause for a large number of students commuting from Cape Town and surrounding areas resulting in a substantial increase in traffic.

Apart from the influence of the University of Stellenbosch, a relative large number of alternative tertiary education institutions and schools in Stellenbosch accommodate both local and commuting students. With the number of university students to be more than 31 000 and taking the number of students from alternative tertiary education institutions and pupils from schools into consideration this number can easily be doubled in a town with a population of 170 000 (Du Plessis, 2018).

Existing infrastructure cannot handle the influx of new residents, students and businesses into Stellenbosch. There is a concern by the Rate Payers Association that, while local authorities are addressing new infrastructural needs through development and urbanisation, Stellenbosch may eventually end up as yet another suburb of Cape Town, very similar to Durbanville, losing its rural character.

Endeavouring to counter the negative impact of urban development in Stellenbosch on the quality of life for residents, students, businesses and tourists alike, Stellenbosch was chosen as case study for this thesis. Figure 32 provides a view one of the streets temporarily closed for vehicular traffic during an event.

Figure 32: Street Soiree event in Stellenbosch where the streets are closed for vehicles during the event
(Photo: A Maritz)

As a resident of Stellenbosch the following observations were made (some of the observations have also been made in previous studies):

1. The use of non-motorized transport is a very popular mode of transport around the whole town of Stellenbosch, but specifically within the central town area (Moody, 2012);
2. The pedestrian volumes are high over the whole town (due to many residents, tourists and students);
3. The leisure area of the town (as defined in Figure 28) is often congested. When visiting this area by car, parking is a problem;
4. The amount of pedestrians noticed in this central area outnumber the amount of cars usually driving through this area or parked in this area;
5. The atmosphere of the central town area is relaxed with visitors in the area strolling through the streets, browsing through the art galleries and sitting at the on-street cafes. This ambience is disturbed by cars driving by;
6. There is a lack of public transport in Stellenbosch; therefore travellers within the town rely on the use of private cars.

A previous study was conducted in this area namely “Traffic Impact of Pedestrianization in Stellenbosch”. Mr W Mohr and Professor SJ Anderson, from the University of Stellenbosch, were responsible to complete this study in 2017 (Mohr, 2017). The results obtained from this study are used to determine the validity of the developed pre-feasibility model where possible. The study is also used to compare the obtained results and to fill in some of the required input fields as required by the pre-feasibility model.

8.3 Application of Pre-Feasibility Model

In this section the developed model is applied to the inner central area of Stellenbosch

Pre-feasibility Model Part 1: Suggested Checklist as Applied to Stellenbosch

The checklist is completed based on known information for the proposed pedestrian area of Stellenbosch.

	Characteristic	Description of Characteristic	Check	Note
Part 1: Compulsory Characteristic	Dense Area	Is the proposed location in a high density residential and commercial area?	√	1
	High Pedestrian Volumes	Does the location currently have high pedestrian volumes (residents, tourists, students)? Will the area be able to accommodate pedestrians with an acceptable LOS after pedestrianization?	√	2
	Parking	Is there space to provide alternative parking at a reasonable price and within close proximity to the pedestrian zone, once the pedestrian zone is implemented?	√	3
	Public Transport Access	Is there easy access to public transport from the pedestrian zone and is the pedestrian zone accessible by public transport? It should be noted that the pedestrian zone should not overlap with a bus route. In the case where the pedestrian zone will be on a bus route, will it be possible to alter the bus routes?	x	4
	Noise Pollution	Is the location prone to noise pollution?	√	5
	Accident Prone	Is the location prone to accidents and accidents typically involving pedestrians?	x	6
	Congested Area	Does the location experience heavy traffic congestion during peak and off peak time periods? It is recommended that there should be alternative routes around the pedestrian area to accommodate the displaced traffic. Further considerations include whether the surrounding intersections will be able to accommodate the new traffic conditions.	√	7
Part 2: Strongly Recommended Implementations	Safety	Will the pedestrian zone be a safe environment during the day and at night time?	√	8
	Physical Improvement	Will the area be improved in terms of aesthetics (planting of trees, adding benches, etc.) and will the physical environment be healthier (less pollution) after pedestrianization?	√	8
	Ambience Improvements	Will the feeling of the area improve in terms of comfort, promote healthy lifestyles, create a sense of community, be relaxed and provide a space for entertainment after the implementation of pedestrianization?	√	8
Part 3: Recommendations	Access Points	The area should provide points of access for emergency and delivery vehicles into the area.	√	9
	Not located on major routes	The proposed pedestrian zone should not be placed on major through routes.	√	10
	Alternative Routes	Alternative traffic routes should be present and in close proximity of the pedestrian zone to accommodate the displaced traffic.	√	10
	Compact Area	The identified area for the proposed pedestrian zone should be compact (should form a coherent shape to some extent).	√	11
	Open Network	The proposed pedestrian zone should preferably be within an open network.	√	12

Discussion of the suggested checklist:

NOTE 1: The proposed pedestrian location is located in a dense area. There are multiple restaurant, cafes, shops, hotels and galleries situated on these streets. There are also apartment buildings and apartments on top of some of the commercial entities.

NOTE 2: The volume of pedestrians in this area is high due to residents, many tourists and students making use of this area.

NOTE 3: According to the previous study by Mr Mohr and Prof Anderson there is adequate alternative space to accommodate the parking of private cars that will be removed from the proposed area. The parking area that will serve as the additional parking is situated approximately 300m away from the central area. In the case where this additional parking area will not be able to provide sufficient parking bays as is, the opportunity exists to construct a multi-story parking garage at this location.

NOTE 4: The forms of transport observed in the Stellenbosch central area include private vehicles, non-motorized transport and taxis. There is no form of public transport available. In general, and in according to the derived checklist this may point to a potential unsuccessful implementation of a pedestrian zone in the proposed area due to difficulty in accessing the area. For the Stellenbosch case this may not be true since the area is already known for high pedestrian volumes as is. The town of Stellenbosch is small enough to access the area by foot and public transport is not needed to gain access as applicable to big cities.

NOTE 5: As a frequent visitor to the area the cars driving past are experienced as a disturbance, especially at times when a quiet meal is enjoyed at one of the street side cafes.

NOTE 6: No data on accidents involving pedestrians in this area could be obtained. Since the reduction in the number of pedestrian accidents is in accordance with the model a compulsory characteristic for a proposed pedestrian zone, this could mechanistically point to potential unsuccessful implementation of a pedestrian zone resulting in senseless conclusions.

NOTE 7: From prior experience, driving through the proposed streets an average speed of 10km/h was obtained. This is a very low speed compared to the speed that can be achieved on the surrounding streets (e.g. 40-60km/h). The main reason for the low speed is the many pedestrians and other road users moving in and out of parking bays and is not a result of congestion. It can be seen as an unlikely route that will be taken when a traveller is heading through the town. The principle of Braess's Paradox will thus still apply (refer to paragraph C.5 for a description of this principle). It is the same as in the case where road users will find an alternative faster route when stuck in traffic.

NOTE 8: The area already complies with these proposed characteristics. It is therefore anticipated that with the implementation of a pedestrian scheme in this area, the circumstances will not decay and only improve from the current situation.

NOTE 9: There will be sufficient vehicle access points to and exit points from the pedestrian zone to accommodate delivery, emergency and waste removal vehicles, as well as vehicles belonging to residents of the area. Provided that the roads included in this area remain one-way streets there will be three access points to and three exit points from the pedestrianized area as illustrated in Figure 33.

Figure 33: Access and exit points for the proposed pedestrian scheme in Stellenbosch

<u>NOTE 10:</u> As discussed under note 7, the surrounding roads operate at higher speeds than the proposed pedestrianized streets. These roads are therefore considered to be sufficient to accommodate the displaced traffic. Figure 34 illustrates the additional roads available. These roads include Dorp Street, Plein Street and Drostdy Street. Dorp Street and Plein Street are considered to be main roads and therefore the proposed pedestrianized streets do not interfere with main routes.

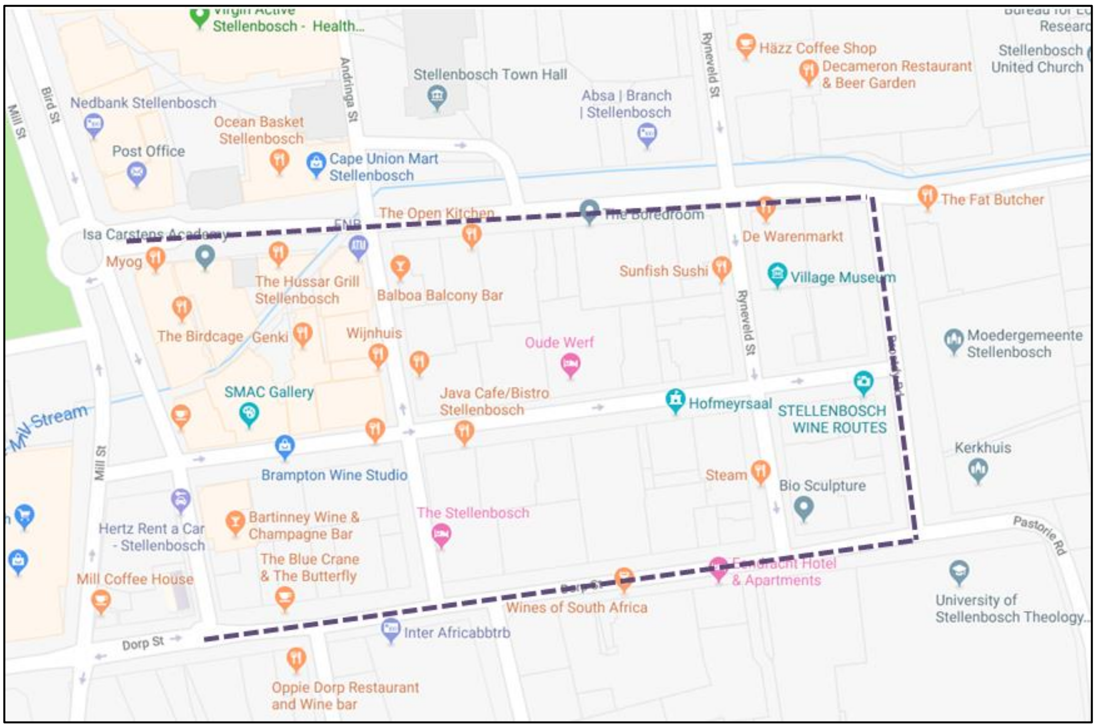

Figure 34: Surrounding roads to accommodate displaced traffic

NOTE 11: The proposed area for pedestrianization is considered compact. The streets that will form part of the area are all intersecting. The circumference of the whole pedestrianized area can be grouped into a rectangular shape as illustrated in Figure 35.

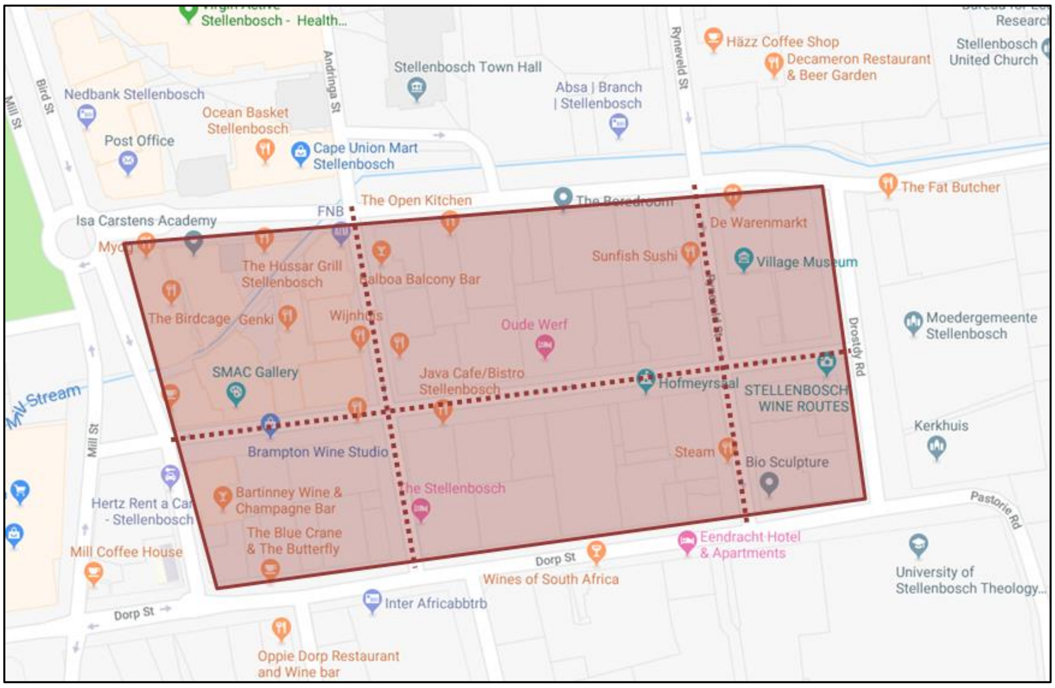

Figure 35: Compact area forms part of the proposed pedestrian scheme in Stellenbosch

NOTE 12: The proposed area lies within an open network. Figure 36 illustrates the different route options available for through traffic.

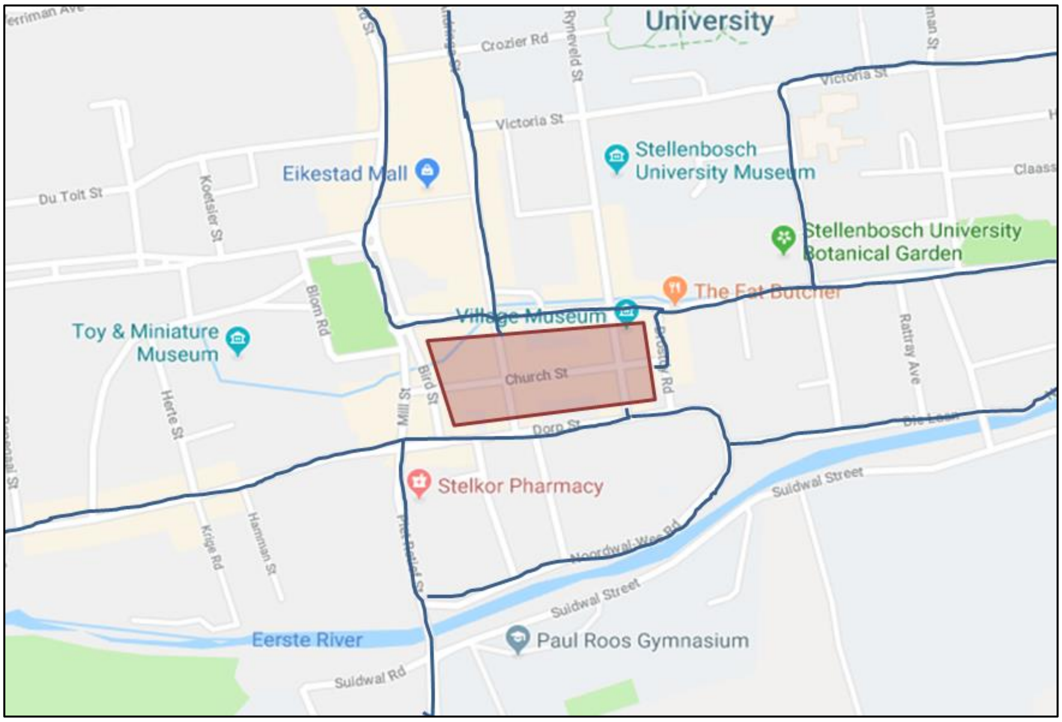

Figure 36: Routes part of the open road network surrounding the proposed pedestrian scheme in Stellenbosch

Pre-feasibility Model Part 2: Suggested Checklist as Applied to Stellenbosch

The second part of the pre-feasibility model, with the input values required by the model and the calculated output values, is presented in this section.

For the first section of air quality, the input value of total road length is equal to approximately 613m, as obtained from Google Earth measurements. The proposed area does not have any pedestrian plazas or squares that will form part of the proposed pedestrian zone; therefore this input value is equal to $0m^2$.

To determine the effects of green engineering technologies on the air quality the input values of total built up area (the effects of green walls are determined where green walls are a portion of the built up area), area green roofs and area of tree cover are required.

The pre-feasibility model takes the input value of ***built up area*** to determine the effects of green walls on the air quality. The total built up area is approximately 50 $000m^2$ as illustrated in Figure 37. This value is the input value for area green walls in the pre-feasibility model.

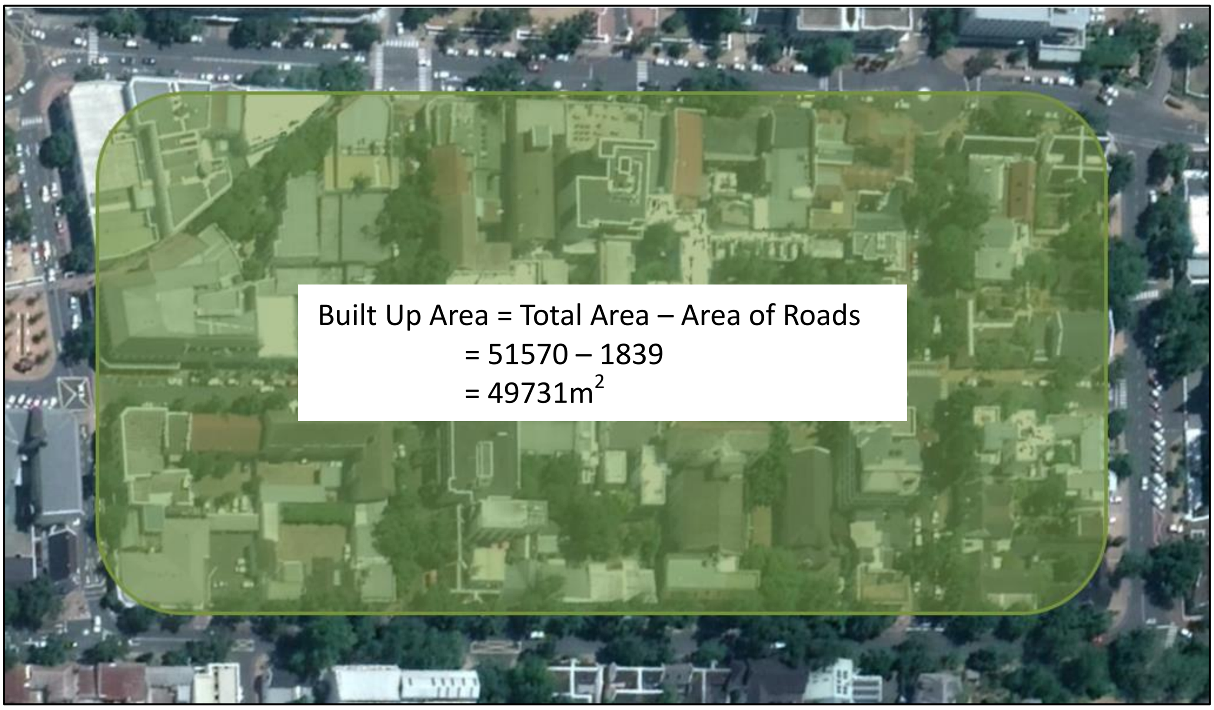

Figure 37: Area of built up area in Stellenbosch town centre

For evaluating the model based on a feasible case study, a number of buildings that could potentially be retrofitted with green roofs were chosen at random. The green roof layout is presented in Figure 38. In the case where this proposed green roof plan is implemented the total green roof area will be $3694m^2$. This is therefore the input value for area of green walls in the pre-feasibility model.

Figure 38: Suggested green roof layout in the proposed pedestrian zone and area of each green roof

There are already trees present in the proposed area. Should any additional trees be planted in the proposed zone and it is assumed to be young and small trees, it is feasible to assume that such trees would typically take up an area of $1m^2$ initially. For evaluating the model based on a feasible case study, an arbitrary number of 30 trees are selected for additional trees to be planted in the proposed area to be pedestrianized. The input value for area of trees will therefore be $30m^2$. Initially the effects of the additional trees are expected to be negligible, but will become more beneficial over time. The completed user interface for the pre-feasibility model for the case of Stellenbosch can be seen in Table 29.

Table 29: Completed pre-feasibility model for the case of Stellenbosch

		User Input		Model Calculations		Model Output	
Air Quality	Vehicular traffic	Total Road Length of Proposed Pedestrianized Area (m)	613	Total Cars removed (no veh / day)	5327	% change in PM	7.73
				Total Road Area (m^2)	1839	% change in HC	-1.49
		Total area of Plazas or Square if present (m^2)	0	Total Pedestrianized Area (m^2)	1839	% change in NO_x	6.80
						% change in CO	8.35
	Green Engineering Technologies	Area of Built Up Area (m^2)	50 000			Mg additional NO_2 removed	462.84
		Area of Green Roofs (m^2)	3694			Mg additional O_3 removed	865.98
						Mg additional PM_{10} removed	821.12
		Area of Trees (m^2)	30			Mg additional SO_2 removed	164.48
						% change in CO_2	1.85

Economy	Model Output	
	Increase in turnover (%)	42.5
	Increase in rent	YES
	Increase in use of public transport	YES

Social	Model Output	
	Increase in perception of good life quality (%)	48.6
	Increase in aesthetics	YES
	Reduction in accidents involving pedestrians	YES
	Increase in amount of pedestrians	YES
	Minimum expected Reduction in Noise Pollution due to Pedestrianization (dB)	10
	Reduction in noise pollution due to green engineering technologies	YES

Traffic	Model Output	
	Reduction in traffic within close proximity of pedestrianized zone (%)	35
	Impact on traffic within outer cordon	YES
	Will traffic evaporation occur?	YES
	Decrease in travel time	YES
	Increase in travel speed	YES

8.4 Evaluation of the Pedestrianization of Stellenbosch according to the outcomes of the Pre-Feasibility Model.

Each part of the pre-feasibility model and the results obtained for the case study are discussed in this section.

Part 1: Suggested Checklist

According to the suggested checklist the proposed area may not be suited for a pedestrian zone based on two factors namely:

1. There is no public transport access to the pedestrian area,
2. No accidents involving pedestrians have been recorded.

There is however no public transport present in Stellenbosch. Since it is a small town with the location of the proposed pedestrian zone in the middle of the town, the area is still accessible by non-motorized transport modes. This factor is therefore irrelevant for this case study.

The second aspect that suggests that the location of the proposed pedestrian zone may not be feasible is the lack of statistics pertaining accidents involving pedestrians. Should statistics become available, this factor may have an influence on the pedestrian zone location, but due to the lack thereof this factor is ignored for this case study.

Part 2: Mathematical Model

Air Quality:

Considering the second part of the pre-feasibility model it is noticed that the air quality will have an overall worsening effect. The only pollutant that will be reduced as a result of the pedestrianization scheme is HC. This pollutant will be reduced by 1.49%. It should be noted that with the previous studies included in the development of the model, the total road length of pedestrianized area was much higher than the road length of the case study. A possible reason for the worsening of air quality can be attributed to the displacement of traffic. With traffic displaced around larger pedestrianized areas the extra travel distance will not have such a significant impact on the air quality. With smaller areas, such as Stellenbosch, the traffic is displaced to the roads precisely parallel to the roads proposed to be pedestrianized. Therefore the air pollution caused by the traffic on the surrounding network will still be present within the pedestrianized zone.

The benefits of green engineering technologies are however very positive and will result in the removal of additional air pollutants.

Economic and Social Benefits:

As discussed in Chapter 4, due to limited data available only predetermined output values of the expected benefits can be included in the model.

Traffic Benefits:

As with the economic and social benefits, due to limited data available only predetermined output values of the expected benefits can be included in the model. The benefits as presented in the pre-feasibility model can however be compared to the results obtained from the study conducted by Mr

Mohr and Prof Anderson. In that study some of the surrounding intersections have been analysed with the aid of a VISSIM simulation (Mohr, 2017). The intersections included in the analysis can be seen on Figure 39: Locations of intersections analysed as adapted from source

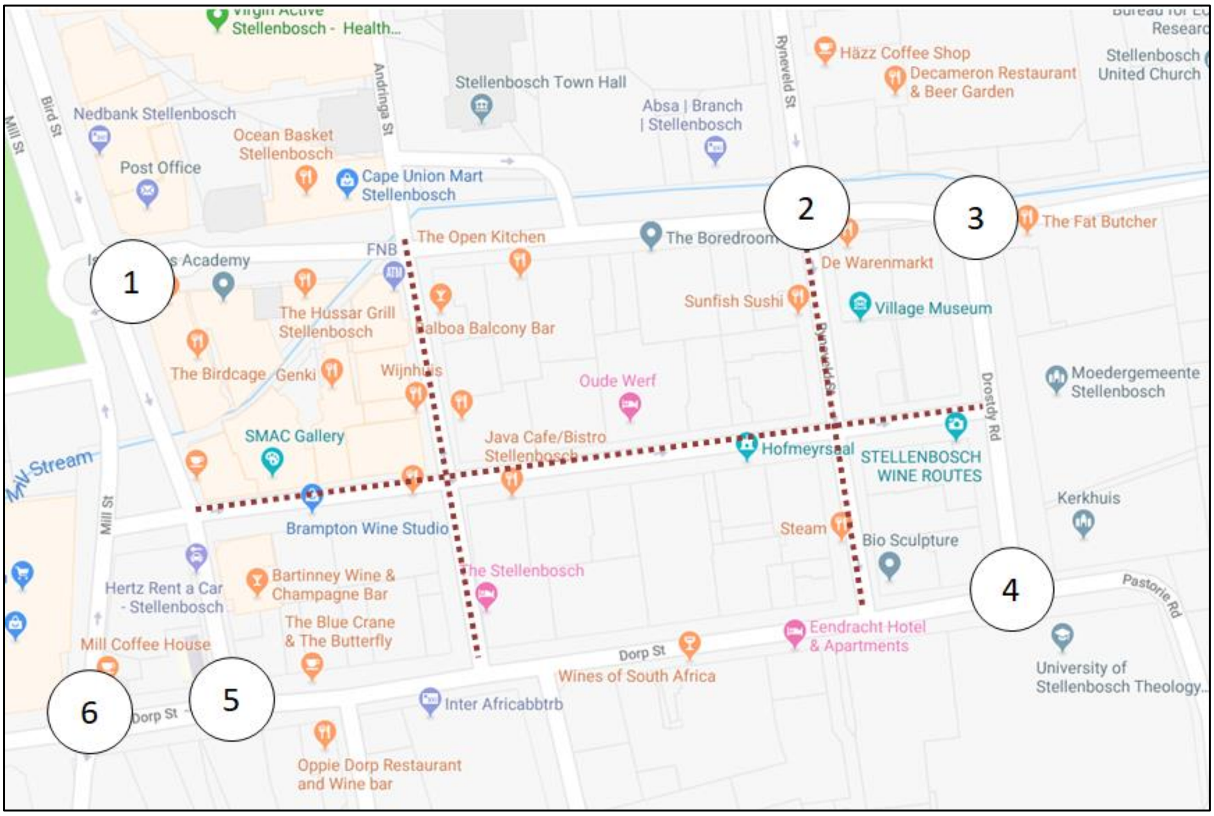

Figure 39: Locations of intersections analysed as adapted from source (Mohr, 2017)

The results obtained for each intersection before and after the proposed pedestrianization are presented in Table 30.

Table 30: Impact of pedestrianization on the surrounding intersections as adapted from source (Mohr, 2017)

Intersection	Before Pedestrianization			After Pedestrianization		
No	LOS	Queue Length (m)	Delay (s)	LOS	Queue Length (m)	Delay (s)
1	C	13.23	15.9	B	8.26	12.08
2	A	1.42	4.96	A	1.49	4.82
3	A	0.93	2.98	A	1.53	3.82
4	A	3.14	6.74	A	2.31	4.72
5	B	9.32	12.85	C	13.73	20.9
6	B	8.04	11.11	C	11.37	16.57
AVERAGE		6.01	9.09		6.45	10.49

From the results it can be seen that the average queue lengths on the surrounding network increased by 0.44m and the average delay for the traffic on the surrounding networks increased by 1.4s. It can therefore be concluded that these results do not agree with the results as presented in the pre-feasibility model. The increase in queue lengths and travel times are however very small and authorities can easily accept these increases as negligible changes. It can therefore be concluded that the proposed pedestrianization scheme, although not leading to better overall functioning of the road network, will have very little impact and cause minimal changes to the operation of the current road network.

9. INDUSTRY CRITIQUE

Semi-structured interviews were held with professionals in the area of city and town planning and strategic transportation planning. The professionals were presented with the pre-feasibility model and asked to provide critique. In this chapter their insights are discussed and incorporated into the pre-feasibility model where possible.

Part 1 of the pre-feasibility model, the Location Determination Checklist, was discussed with Me Nina Otto, a professional City and Town Planner. Part 2, the Mathematical model was discussed with Me Cara Gerber, a professional Transportation and Strategic Planning Engineer.

A semi-structured conversation was also conducted with Mr Sandri and Mr Pelser simultaneously. Mr Sandri is the owner of Wijnhuis restaurant in Andringa Street, located in the proposed area to be pedestrianized in Stellenbosch as the case study. Mr Pelser is the chairman of the Stellenbosch Rate Payers Association. The written consent of the interview participants are provided in Appendix E.

9.1 Critique Regarding the Location Checklist

From the conversation with Me Otto (City and Town Planner), it can be concluded that one of the most important aspects regarding the location of a proposed pedestrian zone is the type of land use. The area where a pedestrian zone is proposed should be described as of “mixed use”, meaning that there should be many trip attractors during the morning peak, for instance work opportunities, retail and even other residential units.

From the conversation with Me Otto the characteristics which should not be present in a proposed pedestrian zone were also noted. These include for example that there should be no vacant plots or areas in the pedestrian zone since these create the feeling of an unsafe and an exposed environment to passing by pedestrians.

Me Otto also provided additional critique and inputs pertaining technical terminology and phrasing as preferred by industry. As final remark Me Otto emphasized the importance of keeping in mind that the model is to determine characteristics of the *location* of the pedestrian zone and not characteristics of the final product, i.e. the *characteristics* of the implemented pedestrian zone.

The inputs from Me Otto have been incorporated into the model. The amended location checklist is presented in Table 31. It is recommended that the amended model is used in future. Since the amendments to the model are more of cosmetic nature, they do not affect the model outcome. It is therefore unnecessary to retest the amended model.

In general Me Otto indicated that the location checklist addresses all necessary aspects.

For some of the typical questions discussed during the semi-structured interview refer to Appendix D.

Table 31: Updated suggested checklist as part 1 of the pre-feasibility model

	Characteristic	Description of Characteristic	Check
Compulsory Characteristic	Dense Area	Is the proposed location in a high density residential and commercial area? Does the proposed area classify as a mixed use area?	
	Awareness of High Pedestrian Volumes	Does the location currently have high pedestrian volumes (residents, tourists, students)? Will the area be able to accommodate pedestrians with an acceptable level of services (LOS) after pedestrianization? Does the observed high pedestrian volumes continue throughout the day?	
	Parking	Is there space to provide alternative parking (park-and-ride facilities or other parking garages), at a reasonable price and within close proximity to the pedestrian zone, once the pedestrian zone is implemented?	
	Public Transport Access (near Public Transport Interchange)	Is there easy access to public transport from the pedestrian zone and is the pedestrian zone accessible by public transport? It should be noted that the pedestrian zone should not be on a bus route. In the case where the pedestrian zone will be on a bus route, will it be possible to alter the bus routes?	
	Noise Pollution	Is the location prone to noise pollution? Does the users of the area feel that the type of noise pollution present in the area is disturbing?	
	Accident Prone	Is the location prone to accidents and accidents typically involving pedestrians?	
	Congested Area	Does the location experience heavy traffic congestion over peak and off peak time periods? It is recommended that there are alternative routes around the pedestrian area to accommodate the displaced traffic. Further considerations include whether the surrounding intersections will be able to accommodate the new traffic conditions.	
	Safety and Security	Will the pedestrian zone be a safe environment during the day and at night time? Is the proposed area free from open areas? Is there sufficient lighting? Does the proposed area have active street frontages?	
Recommended Characteristics	Access and Exit Points	The area should provide points of access and exit for emergency, waste and delivery vehicles into the area.	
	Not located on major routes	The proposed pedestrian zone should not be placed on major through routes. Can traffic be transferred to other routes?	
	Alternative Routes	Alternative traffic routes should be present and in close proximity of the pedestrian zone to accommodate the displaced traffic.	
	Compact Area	The identified area for the proposed pedestrian zone should form a coherent shape to some extent.	
	Open Network	The proposed pedestrian zone should preferably be within an open network.	
	Urban Design	Can good urban design be implemented in the area (i.e. does the area already have active street frontages and trees?)	
	Adverse Weather Coverage	Is there coverage against adverse weather conditions in the proposed area?	

9.2 Critique Regarding the Mathematical Model

In the conversation with Me Gerber (Transportation and Strategic Planning Engineer), the conclusion was that the developed mathematical model can be used without modification. Me Gerber considered this model to be easy, quick and inexpensive to use by anyone (even with limited experience) as decision support tool. According to her the model outcome can potentially be used to motive why a project could be initiated or not and serves as a measure to discriminate between feasible and unfeasible projects when confronted with a large number of projects. She stated that the model can potentially be considered as a useful tool in comparing different project options based on a common standard.

Although no critique was obtained on the model interface, Me Gerber stated that the model could be refined in future research. She strongly recommended that with future research all of the factors currently included in the model could also be translated to a single economic value.

Noteworthy is that Me Gerber agreed that the use of the previous study conducted by Mr Mohr on Stellenbosch may be a good way to test the model. However, the misalignment between his results and the model outcome should not be interpreted as an invalidation of the model as Mr Mohr's study period is shorter than the information period on which the model is based upon.

For some additional information obtained from this conversation refer to Appendix D.

9.3 Critique Regarding the Pedestrianization of Stellenbosch

To get a better grasp on factors the community may consider as important, Mr Sandri (owner of Wijnhuis Restaurant) was consulted for his perceptions on the pedestrianization of the inner town centre of Stellenbosch. The main purpose of the conversation was to verify if the factors listed in the checklist are representative of those considered by him as important and where improvements can be made to the checklist.

According to Mr Sandri the pedestrianization of Stellenbosch may not be as feasible as one would like to believe. He perceives the current vehicle and pedestrian situation to be acceptable in the suggested pedestrian zone and that changes may not necessarily benefit the community within this area, neither socially or economically. His major concern is the possibility that the characteristics of the town centre may change post-pedestrianization to one where alcohol is misused resulting in public bad behaviour. This concern may however be addressed through regulation and bylaws. Provision could be made to limit the land use to the current restaurant and cafe types, and not allowing bars and clubs that could negatively affect the current tranquillity of the area. Other than the possibility of public bad behaviour Mr Sandri agreed with the recommendation that the aesthetics of the area should improve and that the sense of safety and security is an important inclusion in the checklist.

Mr Pelser (Stellenbosch Rate Payers Association) was consulted to determine whether a model such as the pre-feasibility model may be beneficial from a planning perspective. He agreed that this type of model may assist decision makers and may be used in the selection process between potential projects local authorities may want to execute. The discussion with Mr Pelser also included the topic on how a pedestrianization project may be funded. Typically, the project will be identified and incorporated into the Integrated Development Plan (IDP). Funding will then either be obtained from the local municipal budget where tax earnings will be the main source of income or from funding provided by the national or provincial authorities.

10. RESULTS AND INTERPRETATION

In this section the overall results obtained in this study are summarised and interpreted. The results are divided into three main parts as follows:

1. Literature review;
2. The creation of the pre-feasibility model;
3. The application of the pre-feasibility model to Stellenbosch as case study.

1. Literature Review:

From the literature review there is a clear indication that environmental problems do exist in South Africa. Typical causes for these environmental problems are rapid urbanization, urban sprawling and overpopulation. This in turn leads to other environmental problems like air pollution and loss of biodiversity.

With the knowledge of the existence of environmental problems comes the responsibility to address these problems. There are various solutions in addressing environmental problems of which the implementation of pedestrian schemes is one identified for further research. Previous studies of pedestrianization were investigated. The results obtained from these studies indicate that the implementation of pedestrian zones is a feasible method to address some of the identified environmental problems. Pedestrian zones can aid in minimizing air pollution and congestion by providing additional open space. Other benefits such as social and economic benefits are also associated with pedestrian zones.

2. The pre-feasibility model:

The previous studies included in the literature review were analysed in order to identify possible trends and to develop mathematical equations to model the associated benefits of pedestrianization and the application of green engineering technologies. The previous studies were also used to determine the optimum location for a proposed pedestrian zone.

From the previous studies it can be concluded that the success of a pedestrian zone largely depends on the location. Previous studies were consulted to develop a location characteristic checklist to aid in determining whether a proposed area for a pedestrian zone will be feasible or not. The characteristics that may influence the success of a pedestrian zone the most include the land use (the identified area should be of mixed land use), accessibility of the area with public transport, whether alternative roads are available and the sense of safety to pedestrians that will be provided by the pedestrian zone.

In the development of the pre-feasibility model it was further determined that mathematical equations can be developed with linear regression to determine the effects of pedestrianization on air quality. Overall, an increase in the quality of air can be expected as a benefit associated with pedestrianization.

Averages of previous studies pertaining economic, social and traffic circumstances can be determined and are presented in the pre-feasibility model as anticipated and expected benefits. The associated economic benefits that can be expected include an increase of 42.5% in turnover, an increase in rental earnings and an increase in the use of public transport. Expected social benefits are an increase of 48.6% in the perception of a good quality of life, an increase in the aesthetics of the area, less (even zero) accidents involving pedestrians, an increase in the pedestrian count within the area (this will create a sense of community) and the reduction of at least 10dB in noise pollution. Regarding traffic conditions on the surrounding network, it is anticipated that the implementation of a pedestrian scheme will not cause a long term worsening of the traffic conditions on the rest of the traffic network and the concept of traffic evaporation can be expected. A reduction of 35% in traffic within close proximity of the pedestrian zone, a decrease in travel time and an increase in travel speed can be expected, provided that the area of the proposed pedestrian zone adheres to the recommended location characteristics.

The need for a pre-feasibility model as developed in this study was confirmed by obtaining industry critique. Interviews with industry professionals confirmed that the developed pre-feasibility model should be able to aid in the decision making process to proceed with the implementation of a pedestrian scheme or not.

It can further be concluded that the characteristics addressed in the location checklist include those characteristics bringing either total success or total failure and that this checklist provides a good guideline to determine the location of a pedestrian zone.

3. <u>The case study of Stellenbosch:</u>

The developed pre-feasibility model was applied to the inner town centre of Stellenbosch. From the model outputs it is concluded that the identified area of Church Street, Andringa Street and Ryneveld Street adhere to most of the location characteristics. A characteristic shortcoming is that this identified area is not within close proximity of a public transport interchange. The concern is therefore that it will be difficult for pedestrians to move to and from the pedestrianized zone. A positive however is that there are some additional parking within 300m of the proposed zone. The discretion of the decision making authorities should be applied in determining whether this factor will have an influence on the success of the proposed pedestrian scheme. The final decision should be well motivated.

The model outcome with regards to air quality indicate that the pedestrian scheme will have a slight worsening effect on the air quality. This can most likely be attributed to the size of the proposed area. Due to the small size of the proposed area, the pollution caused by the displaced traffic will still be present in the pedestrian scheme. The implementation of green engineering technologies will however contribute to the removal of additional air pollutants.

The predetermined economic and social benefits are expected to be positive based on previous studies.

The model outcome with regards to traffic conditions was compared with a previous study conducted for Stellenbosch. The developed pre-feasibility model indicates that the pedestrian scheme will benefit the traffic conditions on the surrounding network. The previous study however indicates that a slight worsening in the traffic conditions can be expected. Industry critique indicated that the previous study can however not be used to validate the developed pre-feasibility model since the pre-feasibility model is based on data obtained from studies conducted over a longer time frame.

11. OTHER FACTORS TO CONSIDER WHEN CREATING A GREEN PEDESTRIAN ZONE

Due to the broad scope of urban planning, transportation planning and the economy of a country, not all the factors playing a role in the implementation of a green pedestrian zone are included in this study. In this chapter a summative list is provided of other factors to consider in the planning process of a pedestrian zone. The factors included in this list are a collection from multiple sources and conversations with industry professionals. Other factors to consider include, but are not limited to the following:

1. Policies and Legislative Framework:
   - Transport and land use integration and the bigger picture of the transportation planning of an area;
   - Town planning and zoning schemes;
   - Precinct planning;
   - Development policies;
   - Budgets and project allocations;
   - Rates and taxes schemes;
   - The concept of spatial justice;
   - Encroaching of restaurants or cafes onto the sidewalks.

2. Functioning of Pedestrian and Green Pedestrian Zones
   - <u>Parking:</u> Parking cannot be removed completely and methods on how to provide additional or alternative parking should be considered. This can include the building of extra parking garages or park-and-ride-facilities. The number of parking bays available may also have an effect on property value. The provision of either on-street or off-street parking for vehicles requiring special access to the pedestrian zone should be considered;
   - <u>Access permits</u>: Residents, emergency vehicles, delivery vehicles and waste removal vehicles should be granted permits to enter the pedestrian zone;
   - <u>Speed reduction</u>: A much lower speed should be enforced for the vehicles entering pedestrian zones;
   - <u>Non-motorized transport design factors</u>: Provision should be made for people with disabilities by providing bubble blocks at drop kerbs (as seen in Figure 40), audio-tactile sensors at signalised intersections allocated on the outer corners of the pedestrian zone and consideration should be given for bicycle lanes and the right of way for pedestrians. The signage and road markings should also be included in the design factors (Watanabe et. al, 2007).

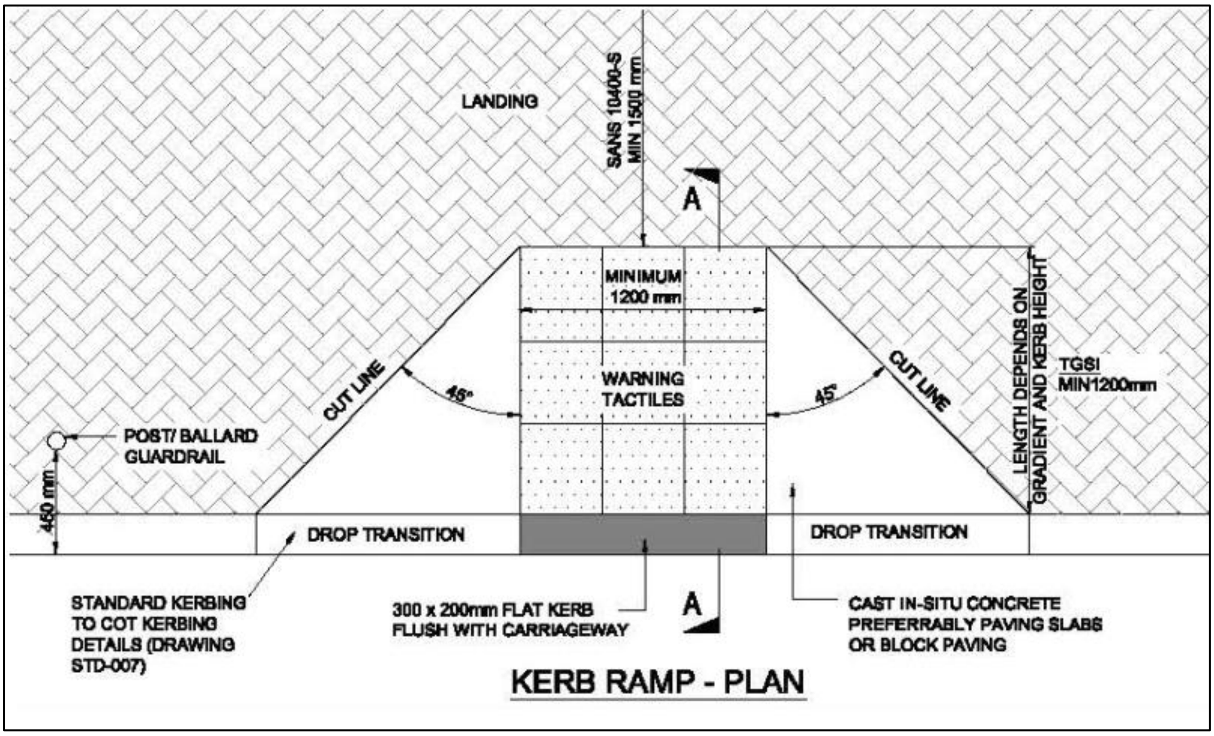

Figure 40: Intersection drop kerb design (Watanabe *et. al*, 2007)

3. Interaction or interfacing between Urban Planning, Public Transport and Pedestrian Zone

   The type of public transport provided in close proximity to the pedestrian zone should be considered. It is typically recommended that non-road based transport (for instance trains) and pedestrian zones function together. This can typically be described as a train terminal with entrances and exits to a pedestrian zone. There should also consideration be given on how the pedestrian zones will be separated from the transit area. This can include urban design features such as bollards or a whole new artificial zone can be created.

4. Acceptance of Pedestrian Zone

   To persuade the community of the benefits associated with the proposed pedestrian zone, good marketing strategies should be followed to include the community in the process. Normally, the implementation of a pedestrian zone may have to be approved by the community through public participation process.

5. Financing of a Pedestrian Zone
   - Financing the proposed pedestrian zone is obviously a very important consideration. An example on how funds could be generated while creating a healthier CBD area is in London where commuters and residents have to pay for the use of a vehicle within the city centre through a special tax (Carvalho, 2017). During an interview with Mr Pelser, the chairman of the Stellenbosch Rate Payers Association, this concept was also discussed. The conclusion was however that the London taxation model may not be feasible in South Africa or a town like Stellenbosch due to the perception that South Africans are already overtaxed. The funding for projects of this nature will either be generated by the municipal

authority itself through existing taxation or allocated through alternative cooperative governmental structures.

- The project development process will typically be to identify and scope the project, followed by incorporating the project into the Integrated Development Plan (IDP). The final step will then be to obtain sufficient funding prior to implementation.

6. Economic Impact on the following aspects should be considered:
    - Tourism;
    - Property Taxes;
    - Gross Domestic Profit;
    - Health Costs;
    - Carbon Taxes.

12. CONCLUSIONS

The creation of green pedestrian zones in overpopulated urban and suburban areas can serve as a solution to some of the major environmental problems faced in South Africa and worldwide.

The primary research question was whether the implementation of a green pedestrian zone can be feasible in an area identified by local authorities. As aid to answer this question, a mathematical pre-feasibility model was postulated based on previous studies.

The study objectives and how the objectives were met are discussed as follows:

1. ***Research the environmental problems faced today in city and town centres and methods to mitigate these problems:***

A literature review was conducted to determine which environmental problems are present worldwide and particularly in South Africa. These problems were found to include, but are not limited to, pollution, global warming, and overpopulation, loss of biodiversity, deforestation and depletion of the ozone layer. Some of the main causes of environmental problems originate in cities and areas of dense population as a result of urban sprawling and rapid urbanization. It is however concluded that there are various methods to address these problems for example public transport, integrative urban design, electric cars and pedestrianization, which was the focus of this study.

2. ***Research previous studies of pedestrian zones and investigate how GPZs may improve environmental conditions, quality of life and whether GPZs is a feasible solution to mitigate some of the negative environmental impacts currently faced in city and town centres:***

Form literature of previous studies is can be concluded that pedestrian zones are a feasible solution to some of the environmental problems. Green pedestrian zones can aid in the improvement of air quality and the absorption of air pollutants. Green pedestrian zones can also add green space to the community and contribute to improvements with regards to the social and economic conditions. Form previous studies the conclusion is made that specific characteristics are required in determining whether a pedestrian zone will be an effective solution.

3. ***Evaluate the best existing green engineering methods to include in green pedestrian zones typical to South Africa:***

In this study research was conducted on existing green engineering technologies. In South Africa the most popular green engineering technologies are green roofs and green walls and therefore these technologies were included in the pre-feasibility model. Form the literature and the pre-feasibility model it can be concluded that the addition of green roofs and walls, as well as the planting of additional trees, will contribute to address environmental problems such as air pollution and the urban heat island effect.

4. ***Develop a model to determine the feasibility of a green pedestrian zone:***

A model was developed that include describing factors on where to locate a green pedestrian zone, what the aspects are to consider when a proposed green pedestrian zone will be implemented and what positive effects can be expected once a green pedestrian zone is implemented.

It can be concluded that there are certain location characteristics that an area should meet for a proposed pedestrian scheme to be successful. The most significant characteristics are that the type of land use in the identified area should be mixed, the proposed pedestrian zone should be able to interface with public transport facilities and the sense of safety and security should be created. It is further concluded that multiple linear regression can be used to model the change in air quality when a green pedestrian zone is implemented. Averages on benefits obtained in previous studies indicate that the proposed pedestrian zone will benefit the economic and social factors of the area as well as the traffic on the surrounding network.

Though the aim was to develop the pre-feasibility model as a mathematical model, the end result includes alternative decision modelling techniques such as a location checklist.

As case study and validation of the model, the mathematical model was practically applied on the town centre of Stellenbosch. From this exercise it can be concluded that Stellenbosch adheres to some of the recommended characteristics but lacking public transport facilities, which is considered one of the "must have" characteristics. It is further found that the pedestrian scheme may have a slight worsening effect on the air quality in total. This could possibly be that due to the small size of the proposed area, the pollution caused by the displaced traffic will still be present in the pedestrian scheme. The implementation of green engineering technologies will however contribute to the removal of additional air pollutants. The predetermined economic and social benefits are expected to be positive based on previous studies.

13. FUTURE RESEARCH

Due to the broad scope of pedestrian zones and the transportation planning industry there are many possibilities for additional research in this field. Not only can the study presented in this thesis be taken further, but new research topics can also be derived from this study.

The following list provides future research opportunities to supplement or enhance this study:

- Obtain results from more additional previous studies in order to expand the data range. This research will contribute to the accuracy of the developed model equations;
- Expand Part 2 of the pre-feasibility model to translate the factors addressed in the model as a single economic value and benefit;
- Develop a third part to the pre-feasibility model that includes a checklist for all legal aspects, policies and frameworks that should be consulted before the implementation of a pedestrian zone;
- Include more green engineering technologies such as green pavement, recycling bins and solar street lighting;
- Develop a model to determine the implementation cost of a proposed green pedestrian zone;
- Conduct a Cost-Benefit Analysis;
- Obtain additional thorough previous studies to validate the developed pre-feasibility model.

Some new research topics developed from this study may include:

- Research how many green pedestrian zones should be implemented in South Africa to neutralize the total carbon footprint of the country;
- How will the growth in green electrical cars impact the need for green pedestrian zones as a measure to address air pollution?

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APPENDIX A: ELABORATION OF ENVIRONMENTAL CONCERNS

In this section a discussion of the following environmental concerns are provided:

A.1 Urbanization and Urban Sprawling as Environmental Concern

Nearly two thirds of the population in South Africa live in urban areas, meeting the definition of urbanization (Edmonds, 2013). Due to the high rate of urbanisation, urban sprawling is inevitable. The environmental and socio-economic cost associated with urban sprawling is unsustainable. The increase in vehicle miles travelled results in the loss of natural resources, an increase in energy consumption and higher levels of air pollution, all contributing to the environmental costs (Musakwa & Van Niekerk, 2018).

Socio-economic costs as result of urban sprawling include the decay of city centres, social and psychological costs and an increase in infrastructure and public service costs (Musakwa & Van Niekerk, 2018). In South Africa, urban sprawling is mainly caused by the lack of accessibility and functional open spaces which is in turn directly related to vehicle miles travelled (Musakwa & Van Niekerk, 2018).

Households located in areas which are close to work, spend less time per day travelling, thus saving costs and emitting less greenhouse gases. Trips also get shorter with an increase in density indicating that more citizens should be located in city centres where shorter trip lengths and times can be expected. Energy efficiency is reduced as the distance between people and buildings increase. In addition, in compact cities the fuel consumption per capita is much less than in low-density sprawling cities. This is another motivation to revitalise city centres in order to make cities more liveable and to reduce sprawling (Musakwa & Van Niekerk, 2018) .

Motivations to counter urban sprawling include (Musakwa & Van Niekerk, 2018):

1. With less vehicle miles travelled, less vehicle emissions and greenhouse gasses are released into the atmosphere, reducing the contribution to climate change;
2. Infrastructure costs per capita decrease with an increase in density;
3. Costs of energy infrastructure can be amortised by the steady source of revenue provided by dense developments;
4. Urban sprawl increases social costs by depriving access to the environment, resulting in the deprivation of interaction between residents. Neighbourhoods become less compact and loses the sense of social vibrancy;
5. Urban expansion brings about losses in natural resources (fauna and flora), farmland, and natural habitats;
6. Urban sprawl can result in the declining of city centres as area for new developments (the city centre is “killed”). As an example, in Durban, developments north of the CBD area are favoured. A similar trend was noticed in Harare, Zimbabwe.

The effect of urban sprawling on urban sustainability is illustrated in Figure A1.

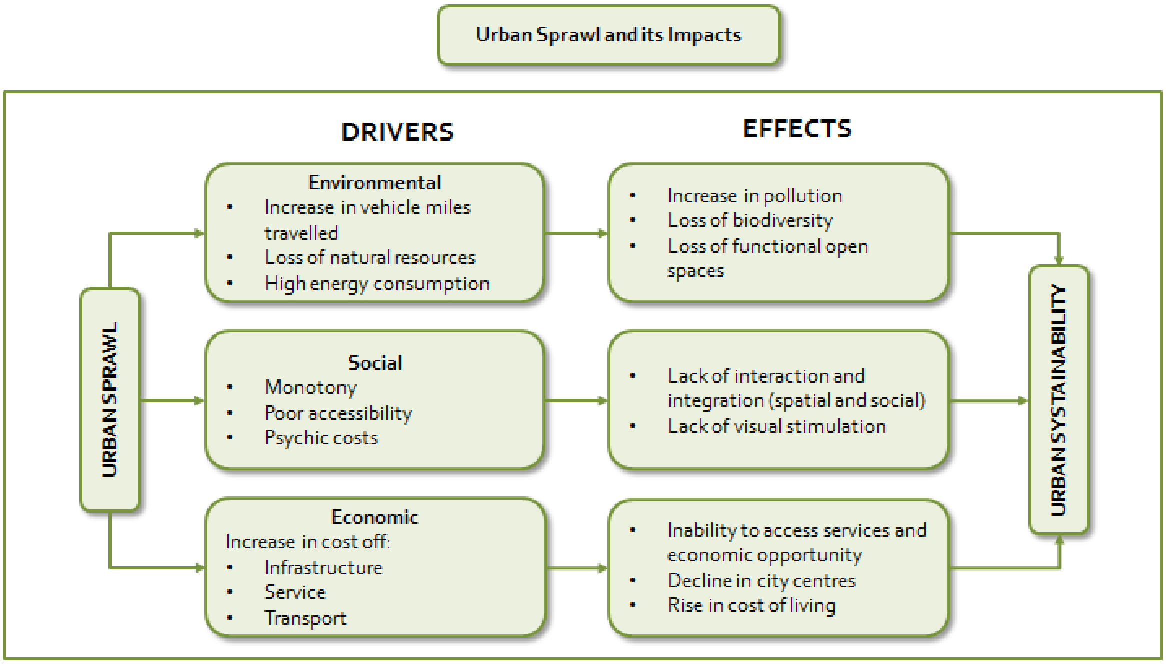

Figure A1: Urban sprawl and its impacts as adapted from source (Musakwa & Van Niekerk, 2018)

A chain reaction of the effects of urbanization is illustrated in Figure A2. From this chain reaction it can be seen that urbanization has an impact on the natural environment that can revert back to the urban city character. The natural environment also has an impact on the economy.

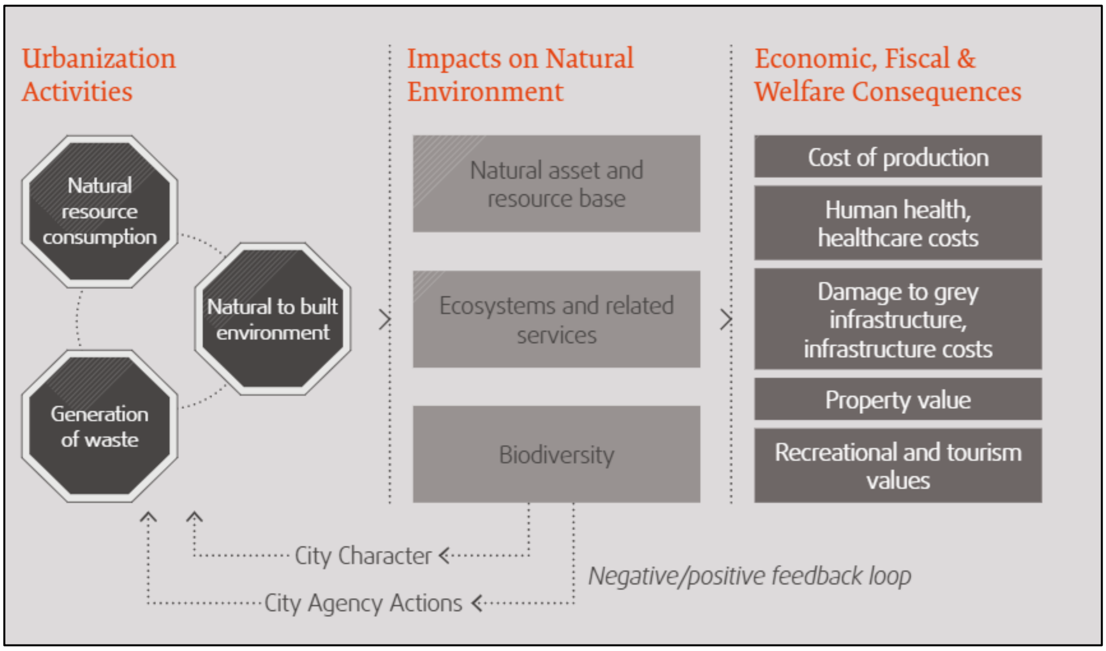

Figure A2: Effects of urbanization (White et. al., 2017)

The effects of urbanization can be summarized as follows:

Urbanisation impacts natural environment → natural environment impacts cities → cities influence living circumstances and therefore welfare.

A.2 Effect of Urbanization on Green Space

In some African cities such as Cairo in Egypt or Luanda in Angola, the green space per capita is $1m^2$. The World Health Organization however recommends that the green space per capita should be at least 9 m^2 and the United Nations recommend at least 30 m^2. Green spaces include public parks, greenways, waterways, and other recreation areas (White et. al., 2017).

In South Africa the trend of urban development encroaching on the natural environment is also apparent. The Durban Bay estuary has been reduced by 57% and only 4% of the natural shoreline and 3% of the mangrove forests still remain (White et. al., 2017).

In addition, it should be noted that urbanization also causes hydrological changes. Rainfall is prevented by roofs, paved areas, roads, buildings and other hard surfaces to infiltrate the soil and thus increasing the rate and volume of storm water run-off. This can lead to river channels becoming eroded or the increase of flood inundation areas. Some of these changes can be attributed to climate change, but the primary cause is the change in land cover. The wetlands, rivers and estuaries of Cape Town, South Africa, underwent transformation and are now systems dominated by reeds due to the additional water brought into the city as an effect of insufficient infiltration.

In South Africa, the cities of Cape Town and Durban are situated within biodiversity rich areas, meaning that urbanization in these cities will negatively affect biodiversity and cause the loss thereof. Every year Durban loses 2% of its terrestrial vegetation. This is one of the results of only 10% of open space in Durban being formally protected. Similarly in Cape Town, 13 plant species have become extinct and 319 species endangered (White et. al., 2017).

A.3 Air Pollution as Environmental Concern

It is important to note that once an environment has been lost it is difficult to rehabilitate it to its natural state. It is however possible for cities to intervene in order to improve the environmental situation. London and Mexico are examples of where the quality of the environment was improved to the benefit of its inhabitants. London implemented strict regulations that prohibit the dumping of pollutants and the directing of sewage and solid waste into River Thames. This resurged river fauna and flora. In Mexico old cars were replaced, lead was removed from fuel, provision of public transport was expanded and the use of natural gasoline was adopted. These efforts drastically reduced air pollution and associated health problems experienced in both London and Mexico. Effectively both the cities became more liveable (White et. al., 2017).

From Figure A3, it can be seen that African cities generate higher levels of particulate matter (PM) compared to other regions. Comparing Johannesburg to cities from developed countries such as London or New York (which are both larger cities than Johannesburg), it is clear that Johannesburg should reduce the amount of particulate matter released into the atmosphere. Noteworthy is that Johannesburg produces more particulate matter per year than what is acceptable by the World Health Organization (White et. al., 2017). Small particular matter includes black carbon, nitrates, sulphates, dust and other pollutants. These particles penetrate the lungs and the cardiovascular system, causing severe health implications. Reduced levels of particular matter are therefore beneficial to all people and the natural environment.

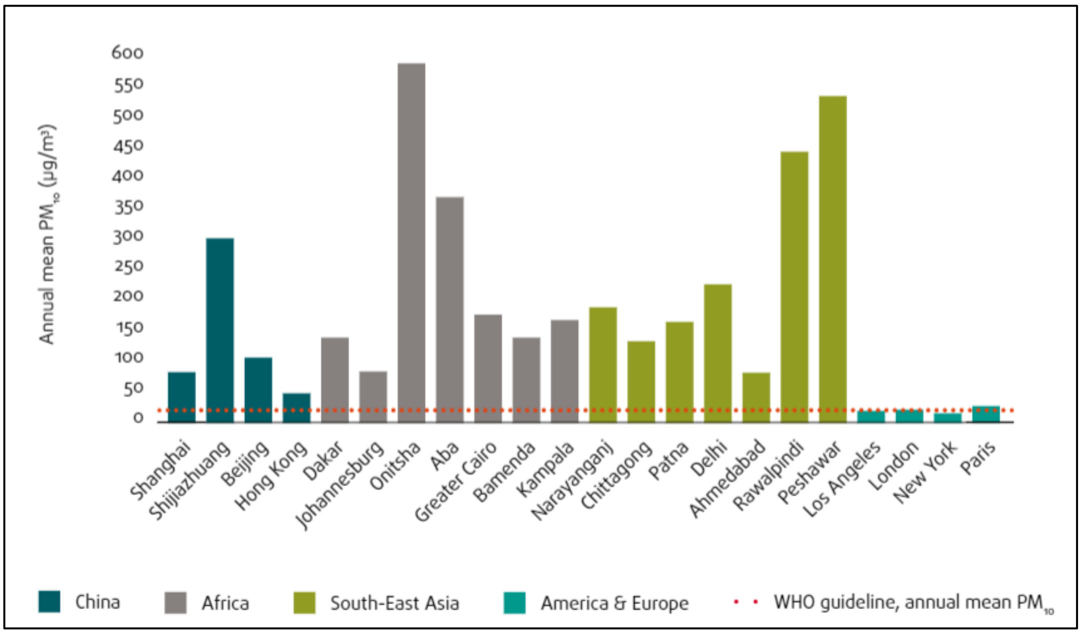

Figure A3: Levels of PM in Asian, African and European cities (White et. al., 2017)

Air pollution was the cause of 5.5 million premature deaths in 2013 (White et. al., 2017). Each year the amount of premature deaths caused by air pollution, increases. In 2010 there was a total of 678 397 premature deaths in Africa caused by air pollution. This figure increased to 712 482 in 2013. This includes household air pollution and ambient particulate matter pollution. In most African countries, formal regulation on air pollution is lacking. According to the latest WHO urban air quality database, 98% of low to middle income cities do not meet the WHO air quality standard. The annual mean concentration of PM_{10} in some South African cities can be seen in Figure A4.

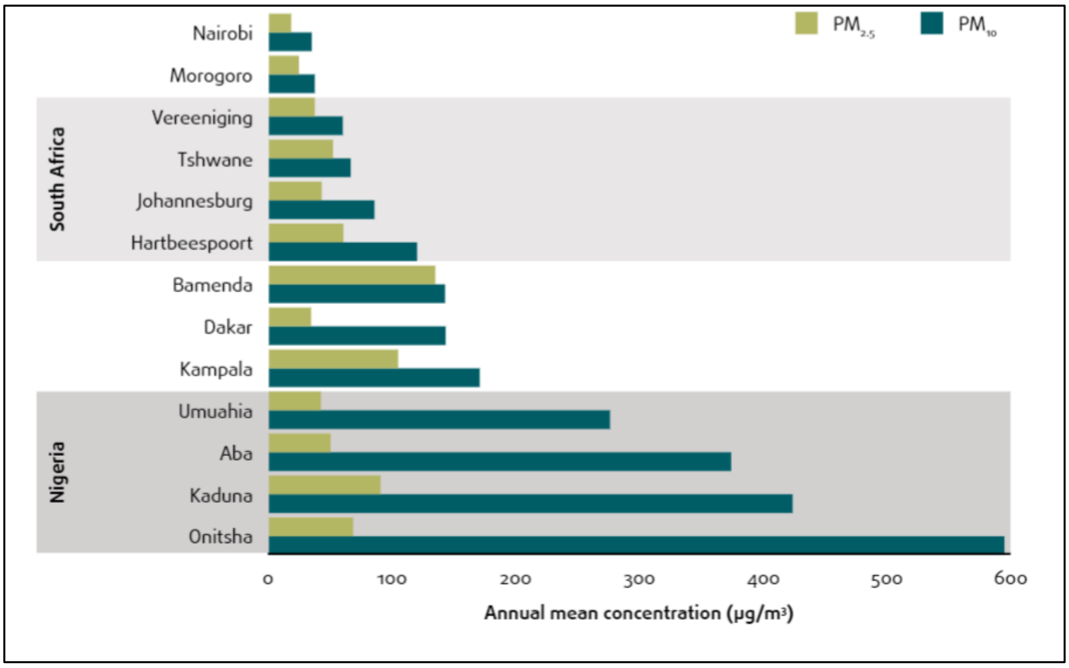

Figure A4: Annual mean PM concentrations in South Africa and Nigeria (White et. al., 2017)

APPENDIX B: POSSIBLE SOLUTIONS TO ENVIRONMENTAL PROBLEMS

In this section a variety of different solutions to environmental problems, as discussed in Chapter 3, is discussed. The possible solutions include the following (Hawley, 2014):

1. Public Transport;
2. Integrative Urban Design;
3. Waste Management;
4. Biomimicry;
5. Low-Carbon Cities, T-Charge, Congestion Tax and Low Emission Zone Charge;
6. Electric Cars;
7. The Paris Agreement;
8. Green Engineering Technologies;

B.1 Public Transport

The city of Curitiba in Brazil introduced the first Bus Rapid Transit (BRT) system as a form of public transport. This initiative opened up 52m^2 of green space per capita (Hawley, 2014). By creating compact transport services with dedicated areas to move in, space is saved. In Figure B1 the BRT of Curitiba can be seen.

Figure B1: Curitiba in Brazil introduced the first Bus Rapid Transit (BRT) (Open Streets, 2017)

B.2 Integrative Urban Design

Integrative Urban Design emphasises the functioning of a system as a whole. In the city of Bogota, Colombia, mobility strategies are integrated into urban design to promote sustainability. Mobility in terms of the transport system can include the integration of bus routes, bicycle pathways and rail lines to function as a connected network (Hawley, 2014). In Figure B2 the dedicated areas for the different modes of transport can be seen as an integrated mobility network.

Figure B2: Mobility in Bogota (Arias, 2015)

In Dar es Salaam, Tanzania, a BRT system was planned specifically with high-capacity and low carbon buses that are cleaner, quieter and more fuel-efficient than conventional buses. This form of integrated design is well suited for public transport. Another example of integrated design can be building constructions that utilise water- and energy-reduction systems and make use of local materials to reduce the use of natural as well as harmful resources (Hawley, 2014). Figure B3 provides an example of the BRT system in Tanzania.

Figure B3: Dar es Salaam BRT (Capital Markets in Africa, 2015)

B.3 Waste Management

The city of Curitiba, Brazil, established a garbage purchasing programme. This programme consists of small trucks traversing informal settlements to collect garbage and recyclables as seen in Figure B4. Residents are also provided with the opportunity to exchange their garbage for food and other necessities (Hawley, 2014).

Figure B4: People in Curitiba lining up to exchange their waste for bus tickets or food (International New Town Institute, 2018)

B.4 Biomimicry

Biomimicry is a scientific approach that utilizes nature as an example on how to design. In the city of Harare, the Eastgate retail and office park was designed to mimic the African termite mounds that can cool themselves as demonstrated in Figure B5 (Hawley, 2014).

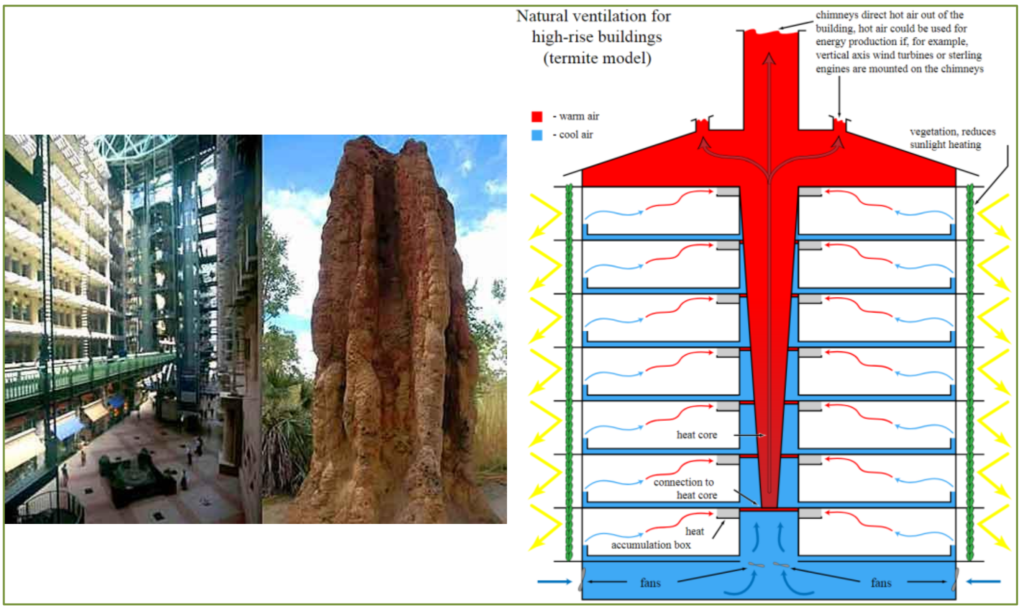

Figure B5: Harare Eastgate Centre (Doan, 2012)

B.5 Charges and Regulations as Incentive to Reduce Air Pollution

In the cities of Dubai, United Arab Emirates and Masdar[1], green space and "walkable neighbourhoods" are incorporated into the city planning as an aid to lower carbon emissions and to achieve their net-zero emission goals (Hawley, 2014). Dubai and Masdar also include urban agriculture and water reuse systems in their planning. Other cities monitor emission releases with greenhouse gas inventory systems to assist in the reduction of carbon emissions.

The city of London realised the impact of air pollution on the health of inhabitants including the cause of lung problems amongst children (Carvalho, 2017). As a solution London introduced a charge, namely the T-charge, on the older vehicles (models before 2006) that causes the most pollution. Motorists needing to drive within the city centre are also subjected to congestion tax. Both of these fees are implemented weekdays from 7am to 6pm as a measure to discourage excessive driving and to improve the air quality (Carvalho, 2017).

Additionally to the fees charged for driving in the city centres, Low Emission Zones (LEZ) are implemented as a further aim to minimise air pollution. Figure B6 shows the location of the LEZ in the London area. These zones operate 24/7 and cover most of the greater London. In Low Emission Zones motorists are charged with a daily LEZ charge. This charge is implemented to discourage the use of polluting vehicles (Transport for London, 2018).

Figure B6: Low Emission Zone (Carvalho, 2017) **and location** (urbnblog, 2018)

In South Africa, the National Treasury released a carbon tax bill in the hope to assist in reducing greenhouse-gas emissions and to ensure that South Africa meets the nationally determined contribution commitments under the Paris Agreement. The carbon tax bill will hold consumers and firms accountable for their production of greenhouse emissions (Burger, 2017).

[1] *Masdar City is located in Abu Dhabi, and is designed to be the most environmentally sustainable city in the world*

B.6 Electric Cars

Replacing ordinary fuel driven cars with electric cars can also be a long term solution to air pollution. An increase was also noticed in the use of electric busses and electric two-wheelers as mode of transportation in the greater London area (Transport for London, 2018).

B.7 The Paris Agreement

Adhering to the "Paris Agreement", means agreeing to contribute in the process to decrease carbon emissions worldwide. Within the renewable energy sector the new emphasis is on the provision of "climate-safe energy solutions". In order to limit the global temperature rise to below 2°C, renewable energy supply has to grow by 65% before 2050. Progress in the renewable energy sector is being made to ensure a low carbon future. Alternative resources (such as biofuel) and alternative energy generating technologies (such as wind turbines) should be used (IRENA, 2017). Not only does renewable energy have benefits to the environment, but can also help to reduce poverty in developing countries. In 2016, 9.8 million people were employed in the renewable energy sector (IRENA, 2017).

Other than renewable energy technologies, green building improvements are also needed to keep the Paris Agreement on track. 39% of carbon dioxide (CO_2) emissions can be attributed to building and construction. With the fast growth in population, a growth in infrastructure is expected, resulting in many future building and construction projects which should be candidates for green building engineering technologies. The global total built-up floor area of 235-billion square metres, determined in 2016, is expected to double over the next 40 years (Van Wyngaardt, 2017).

Realising the importance of green buildings, the Western Cape Department of Transport and Public Works has invested R152-million in a green building for their new regional offices, as seen in Figure B7. This building has earned 5 stars from the Green Building Council of South Africa (GBCSA). This facility aims to use less water, generate less waste and provide a healthier living and working environment for occupants (Kilian, 2017).

Figure B7: Architect's impression of Western Cape Department of Transport and Public Works R152-million investment in a green building for their new regional offices (Western Cape Government, 2015)

B.8 Green Engineering Technologies

Green roofs and green walls are examples of green engineering technologies. Both green roof technologies and green walls provide significant economic, social and environmental advantages especially in cities. The owners of buildings where these technologies are implemented will also receive a return on investment in terms of lower operating costs for the buildings (greenroofs.org, 2018). Figure B8 provides an example of a typical green roof.

Figure B8: Green roofs in the city of Denver (ProudGreenBuilding, 2017)

The proven benefits of green roofs and green walls include the following (greenroofs.org, 2018):

1. Improved aesthetics;
2. Improved exterior and interior air quality;
3. Improved energy efficiency;
4. Protection for the built structure;
5. Noise reduction;
6. An increase in biodiversity;
7. Increased health and well-being;
8. Growth in urban agriculture;
9. Contributes to storm water management;
10. Moderates the urban heat island effect;
11. Reduction of electromagnetic radiation;
12. Retardation of fires.

APPENDIX C: DESCRIPTION OF PREVIOUS STUDIES

In this section the previous studies included in the research to develop the pre-feasibility model, are discussed.

C.1 The Effect of Pedestrianization on Air Quality

The effects of pedestrianized schemes in the following five cities are included in this section:

1. Chester,
2. Nuremburg,
3. Oxford,
4. Istanbul,
5. Katerini and Rhodes.

1. The Chester Case

In a transport and travel research study for Chester, UK, it was found that traffic flow characteristics and the speed at which vehicles travel as part of the transportation system in urban areas are the primary cause for air and noise pollution (Chiquetto, 1997).

The study researched how the implementation of a pedestrianization scheme could impact the environment. The rate at which emissions are released by vehicles were found to be much higher in congested areas where the principle driving pattern is that of acceleration followed by deceleration movements. These movements are typically found in urban areas, where pedestrian activities are also expected (Chiquetto, 1997).

The entire urban and road network of Chester was considered. The urban network is provided in Figure C1, where the solid dark lines indicate roads in the area where the pedestrianization scheme has been implemented.

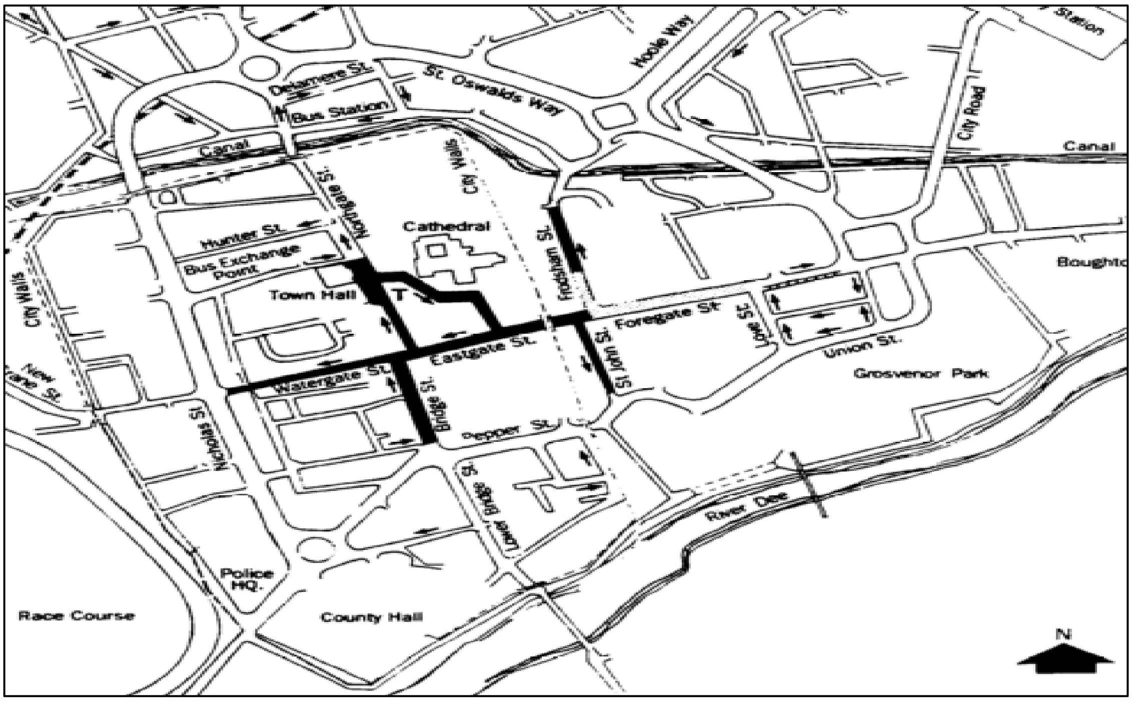

Figure C1: Chester case study pedestrianization scheme (Chiquetto, 1997)

Traffic contributes significantly to the release of greenhouse emissions, of which the primary emissions include carbon monoxide (CO), hydrocarbons (HC), carbon dioxide (CO_2), oxides of nitrogen (NO_x) and particular matter (PM). These emissions were investigated and were measured in kilograms per hour. As part of the implementation of the pedestrianization scheme in the central area, traffic in the central area was diverted to the surrounding network. The primary characteristics of traffic contributing to air and noise pollution are traffic flow, speed, travel distance and level of congestion.

The emissions in the total network and central area before and after the closure of the central streets for traffic were measured and are presented in Table C1. The percentage difference in each of the emissions before and after pedestrianization is also provided (Chiquetto, 1997).

Table C1: Emission counts of Chester case study

Before				Percentage Change				After			
Central Area		Total Network		Central Area		Total Network		Central Area		Total Network	
Emission	kg/h	Emission	kg/h	Emission	%	Emission	%	Emission	kg/h	Emission	kg/h
CO	200	CO	1000	CO	-6.5	CO	4.5	CO	187	CO	1045
HC	50	HC	250	HC	-6	HC	4.5	HC	47	HC	261.25
NOx	30	NOx	200	NOx	0.5	NOx	5.5	NOx	30.15	NOx	211
CO2	5300	CO2	30600	CO2	-5	CO2	5	CO2	5035	CO2	32130
PM	1.8	PM	20	PM	5.75	PM	6	PM	1.9035	PM	21.2

From the data presented in Table C1 it can be seen that there was a slight decrease in the total greenhouse emissions produced in the central area, except for NO_x and PM. The average decrease is approximately 5% after pedestrianization. Although, after pedestrianization there would be no more emissions in the pedestrianized area, the surrounding roads continued to accommodate traffic. Busses were diverted form the pedestrianized roads to routes outside of the central area. These routes were often longer than the original bus routes causing additional emissions. Busses were therefore regarded as the main cause for an overall increase of about 5% in emissions in the total network and produced more PM than before pedestrianization, notwithstanding a decrease of emissions in the pedestrianized zone.

It should be clear from the findings above that users of the pedestrianized scheme should have major environmental benefits in terms of air pollution. The emission concentrations in the area of only pedestrian access roads have on average been reduced between 70% and 80%.

Since the pedestrianized solution however resulted in a small increase in emissions of 5% in the total network due to the diverting of busses, it is therefore important to consider the actual location of a pedestrian zone. A summary of all the results obtained in this study is graphically presented in Figure C2.

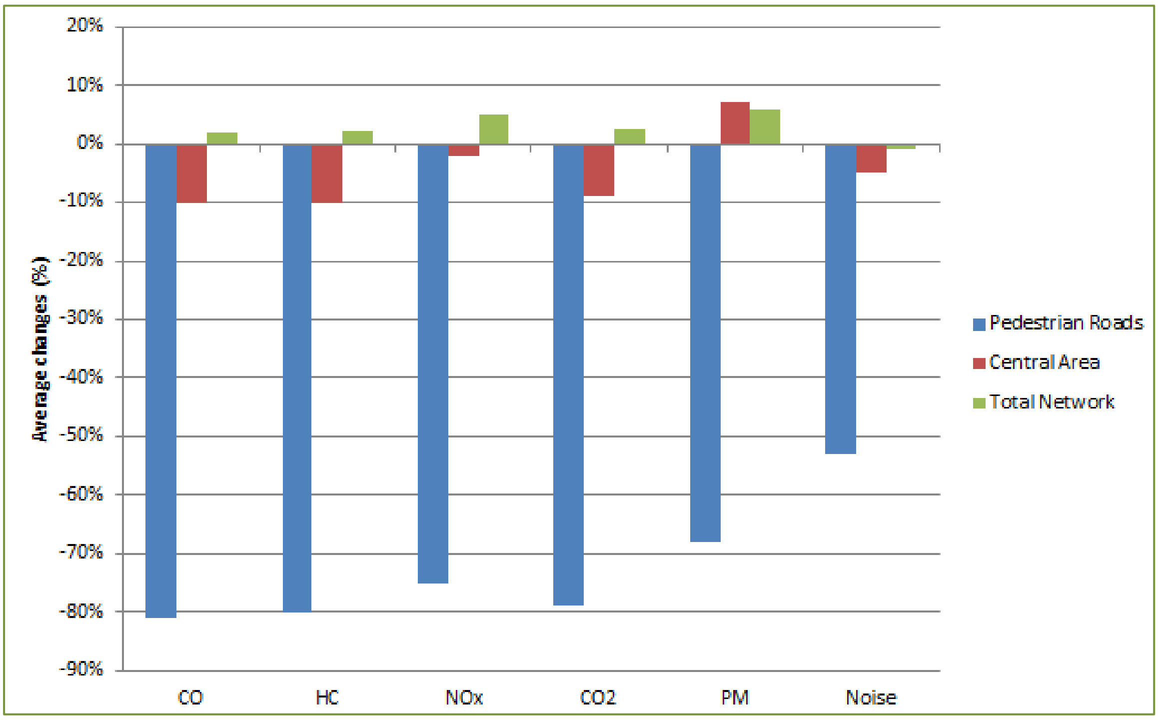

Figure C2: Summary of results for pedestrianization in Chester as adapted from source (Chiquetto, 1997)

2. The Nuremberg Case

The historic city centre of Nuremberg, Germany was pedestrianized in 1970. In Figure C3 it can be seen that the centre of the Old Town is completely dedicated to pedestrians. Before pedestrianization, 25 000 vehicles moved through Rathausplatz/Theresienstrasse Square over a period of 16 hours. This resulted in the worsening of air quality, causing health problems and the decay of historic buildings.

Figure C3: Nuremberg pedestrianized Old Town (Dombrowski, 2018)

The streets of Nuremberg that were pedestrianized are graphically indicated in Figure C4.

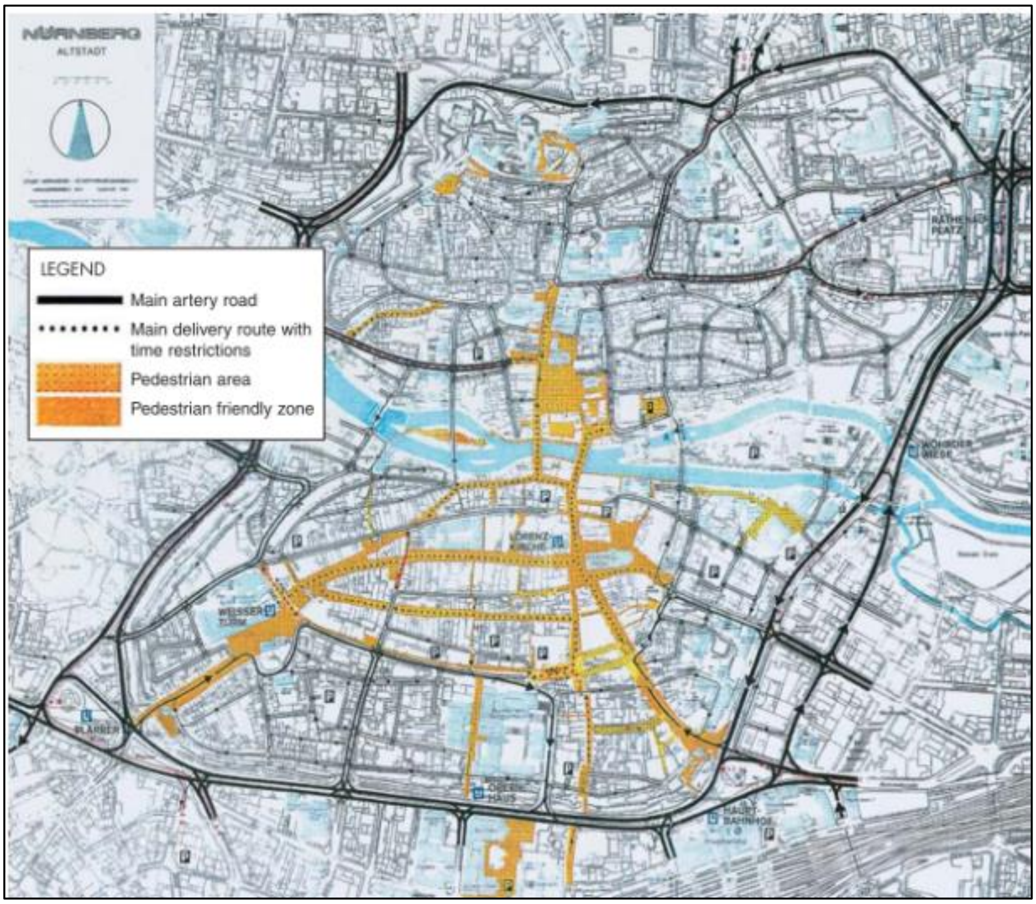

Figure C4: Pedestrianized streets of Nuremberg (Wallztrom, 2004)

Table C2 provides the change in air quality due to pedestrianization in the city of Nuremberg. The weight of air pollutants are given in μg/m^3 before and after pedestrianization (Wallztrom, 2004).

Table C2: Impact of pedestrianization on air quality in Nuremberg

Pollutant	Data for 1982/83 BEFORE pedestrianization (μg/m^3)	Data for 1988/89 AFTER pedestrianization (μg/m^3)	Percentage Change (%)
Sulphur dioxide (SO_2)	33	28	-15.15
Nitrogen monoxide (NO)	122	86	-29.5
Nitrogen dioxide (NO_2)	100	61	-39.0
Nitrogen oxides (NO_x)	139	90	-35.3
Carbon monoxide (CO)	3400	2980	-12.4
Particulate Matter (PM)	77	64	-16.9
Lead (Pb)	0.249	0.248	-0.4

3. The Oxford Case

High Street in Oxford, UK was closed for cars in 1999, motivated by the deteriorating environmental conditions such as the increased air and noise pollution due to the increasing number of cars. The deteriorating environmental conditions negatively impacted the historic nature of Oxford and the quality of life of habitants. Pedestrians walking in High Street can be seen in Figure C5. Pedestrianization had a very positive impact and air quality improved substantially (Wallztrom, 2004).

There was a 25% reduction in PM and 75% decrease in CO (Wallztrom, 2004).

Figure C5: Oxford High Street (Milasan, 2014)

4. The Cambridge Case

Cars were restricted from using some of the through routes in Cambridge, England. Figure C6 indicates the pedestrianized streets of Oxford and Cambridge.

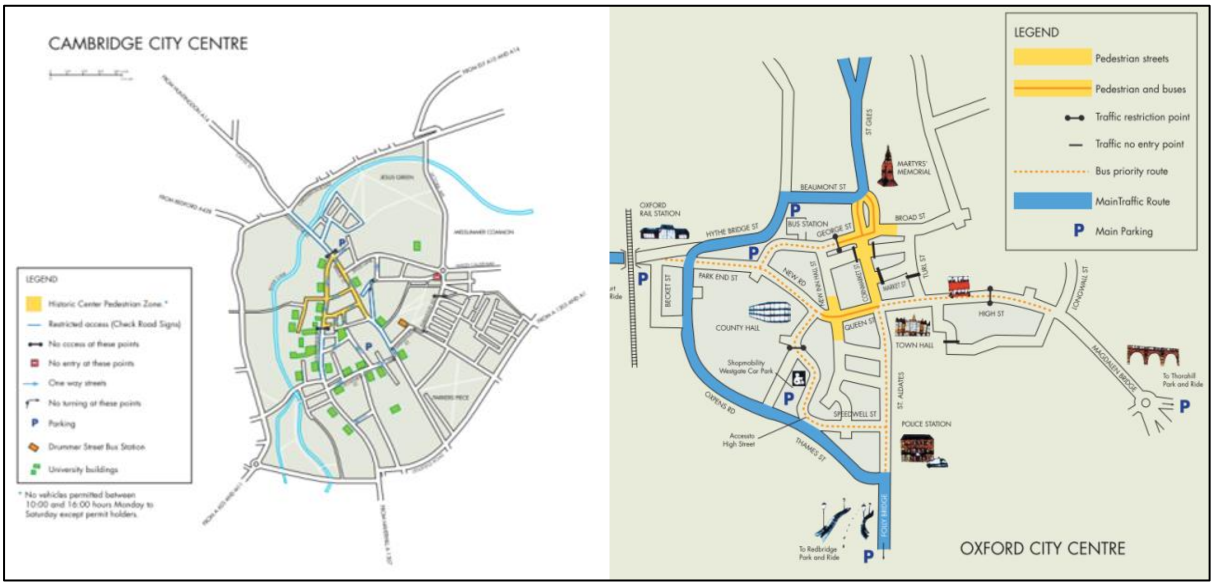

Figure C6: Pedestrianized streets of Oxford and Cambridge (Wallztrom, 2004)

The high volumes of pedestrians (students of Cambridge University and tourists) together with the historic architecture and narrow streets made travelling by car difficult. Poor air quality was also a concern since pollutants caused by high levels of congestion got trapped in the "canyon" streets (Wallztrom, 2004).

There was a 5% decrease in Particulate Matter recorded due to pedestrianization of this area.

5. The Istanbul Case

The Historic Peninsula of Istanbul, Turkey, is surrounded by the Golden Horn, Bosphorous River, the Byzantine City Walls and the Sea of Marmara, making this the home of four UNESCO World Heritage Sites. This area is both a central commercial area of Istanbul, also attracting vast numbers of tourists, and a dense residential area. It was therefore important to acknowledge that air pollution can cause serious impairments on this valuable area (Üzümoğlu *et al.*, 2015).

In 2005, the City of Istanbul commenced with a pedestrianization project to negate the negative impacts associated with vehicle traffic and commercial activities. Studies were conducted to evaluate how pedestrianization altered local air quality. Measurements of the air quality were taken prior and post pedestrianization. In Figure C7 the streets that were pedestrianized are indicated in Cyan blue.

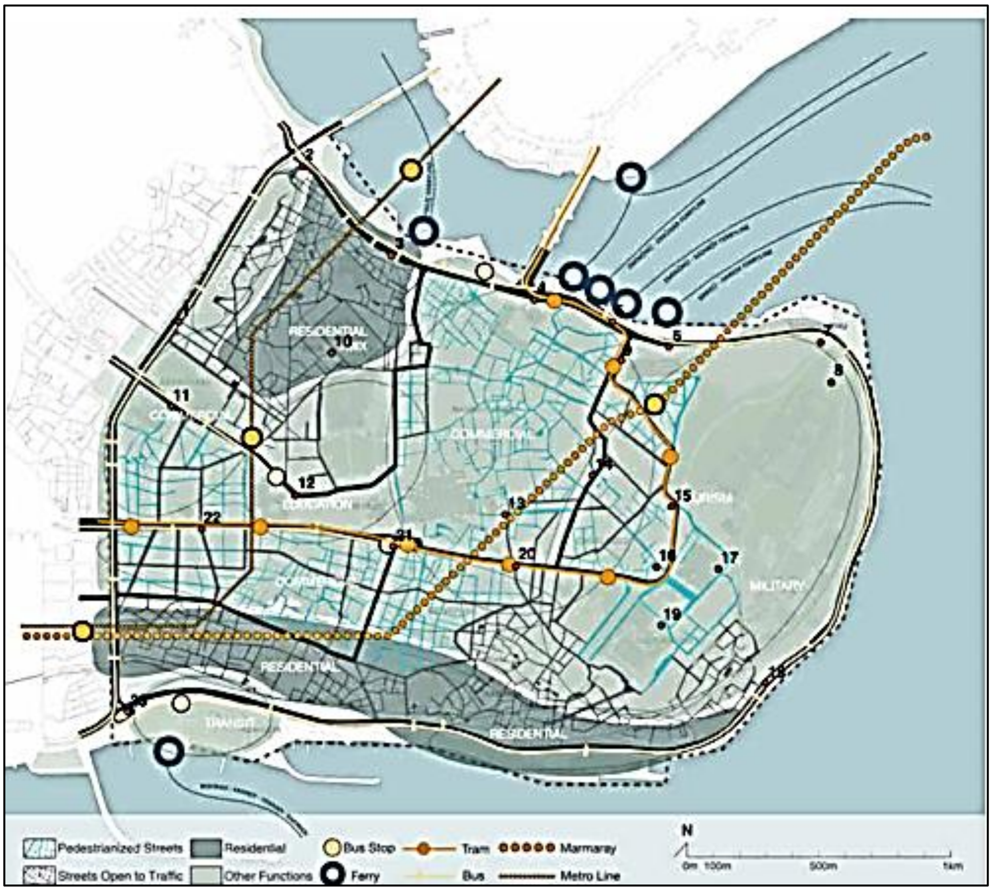

Figure C7: Pedestrianized streets in the historical peninsula of Istanbul (Üzümoğlu et al., 2015)

The measurements related to the improvement of air quality due to pedestrianization are presented in Table C3.

Table C3: Change in air pollutants before and after pedestrianization of the historical peninsula in Istanbul

Pollutant	Data for 2010/11 BEFORE pedestrianization ($\mu g/m^3$)	Data for 2014/15 AFTER pedestrianization ($\mu g/m^3$)	Percentage Change (%)
Sulphur dioxide (SO_2)	23	3	-86.96
Nitrogen dioxide (NO_2)	82	56	-31.71
Particulate Matter 10	265	125	-52.83

The authors of the abovementioned study concluded that bus routes should be removed altogether from the central part of the peninsula (Üzümoğlu *et al.*, 2015). This finding is also aligned with the findings in the Chester case elaborated upon previously.

6. The Katerini and Rhodes Cases

In another study, pedestrianization schemes were implemented in the central city areas of two cities in Greece to address environmental and traffic problems. The first was for the city of Katerini in northern Greece and the second for the island of Rhodes.

Traffic problems included pedestrian flow volumes, growth in traffic volumes, improper geometric characteristics and the need to bypass the city, leading to the implementation of the pedestrian schemes (Brebbia, 2000).

Issues experienced in central Katerini leading to pedestrianization included:

1. Through traffic (heavy traffic volumes) passing via the commercial centre;

2. Bypass route alternatives were limited;

3. A road hierarchy was absent;

4. Inhabitants living along the streets in the city centre were negatively influenced by the heavy traffic (noise pollution, air pollution, visual intrusion, accidents).

The city of Rhodes faced severe traffic and high tourist volumes during summer months. This led to environmental problems threatening the old city. A pedestrianization scheme was proposed in the part of the old city where commercial activities took place. In Figure C8 the pedestrianized scheme of Katerini is provided and in Figure C9 that of the Island of Rhodes.

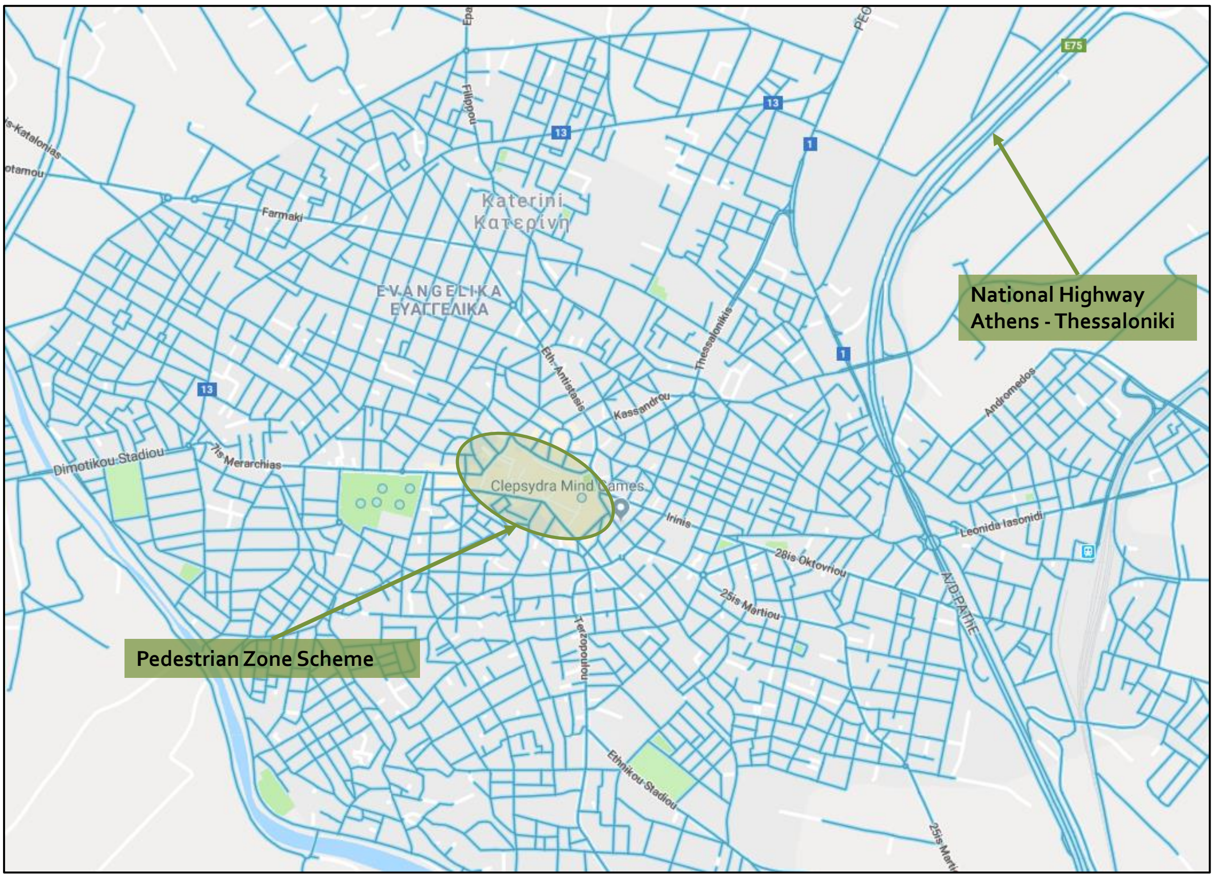

Figure C8: Katerini, Greece, pedestrian scheme (Brebbia, 2000)

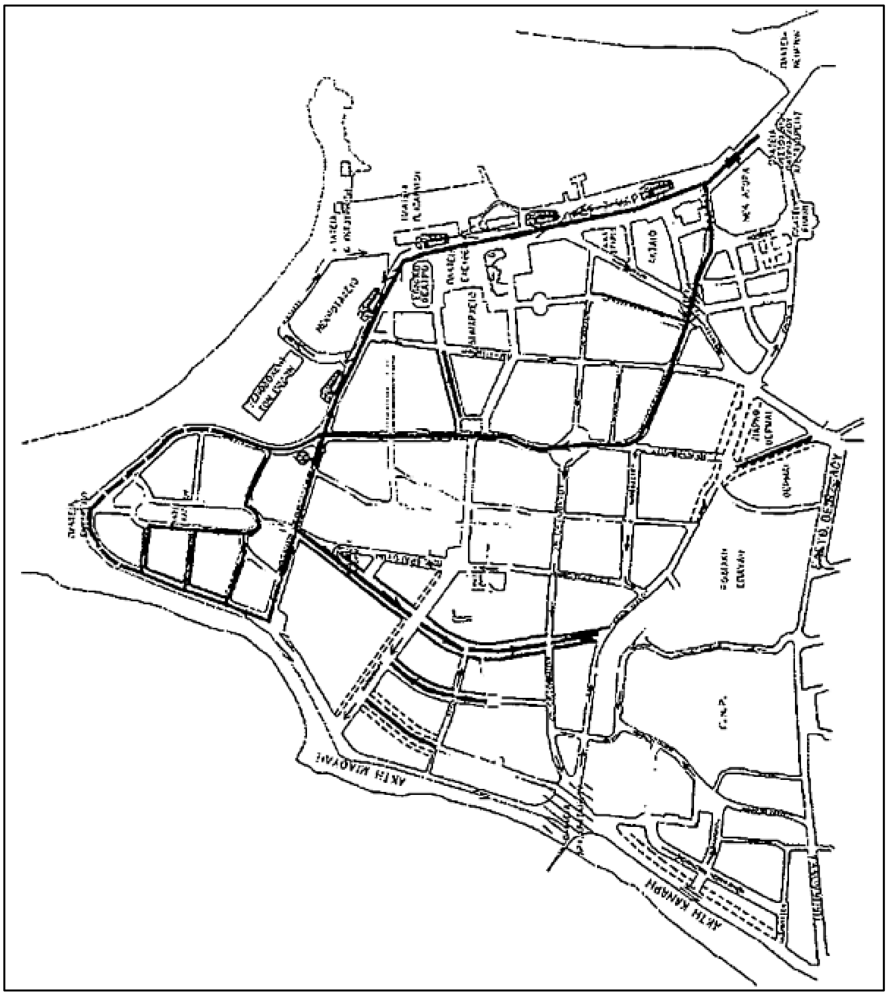

Figure C9: Island of Rhodes, Greece, pedestrian scheme (Brebbia, 2000)

The implementation of pedestrianization schemes led to significant decreases in the amount of air polluting emissions in both cities as seen in Table C4. Secondary benefits of pedestrianization included reduction in fuel consumption and traffic delays (Brebbia, 2000).

Table C4: Positive consequences of pedestrianization of Katerini and Rhodes, Greece

Pollutant	% improvement Rhodes	% improvement Katerini
NOx	45.6	35
HC	32.3	25
CO	43.8	17.2
Fuel consumption	24	-
Average delay per vehicle	55.4	-

In 42% of accidents experienced on the road networks of Greece a single vehicle and a pedestrian are involved. To improve traffic safety a strategy of completely separating cyclist and pedestrians from cars was developed.

From the Katerini and Rhodes cases it can be concluded that pedestrianization schemes are efficient methods to improve the overall environment and air quality. A significant reduction was observed in the values of NO_x, HC and CO in the pedestrianized areas. The environmental benefits in these cases can be attributed to the on-street parking policy that was implemented in the greater road network together with parking stations in the city centre perimeter (Brebbia, 2000).

Table C5 provides a summary of all the results obtained from previous studies. These results are analysed and interpreted in Chapter 7 in order to incorporate the effect of pedestrian schemes on air quality.

Table C5: Summary of changes in air pollutants in previous studies due to pedestrianization

Case Study	% Change in Pollutant								
	CO	HC	NO_x	CO_2	PM	SO_2	NO	Pb	NO_2
Chester	-6.5	-6	+0.5	-5	+5.75	-	-	-	-
Nuremberg	-12.4	-	-35.3	-	-16.9	-15.15	-29.5	-0.4	-39
Oxford	-75	-	-	-	-25	-	-	-	-
Cambridge	-	-	-	-	-5	-	-	-	-
Istanbul	-	-	-	-	-52.83	-86.96			-31.71
Katerini	-17.2	-25	-35	-	-	-	-	-	-
Rhodes	-43.8	-32.3	-45.6	-	-	-	-	-	-

C.2 The Effect of Green Pedestrian Zones on Noise Pollution

Noise pollution is mainly caused by the geometry of the road network, the buildings adjacent to the roads with noise reflecting facades in addition to the amount of road junctions and the distance between junctions (Chiquetto, 1997). Three scenarios are included as part of the research on noise pollution namely:

1. Chester,
2. Durham and Leeds,
3. Green walls.

1. The Chester Case

The pedestrianization scheme in Chester, UK contributed to the reduction of noise pollution. Before the implementation of the pedestrianization scheme, noise levels ranged between 80 and 82 dB(A), which is higher than the recommended 70 dB(A) over a period of 18 hours. After the pedestrianization scheme has been implemented noise levels were reduced by an average of 50%, as seen on the graph in Figure C2 (Chiquetto, 1997).

2. The Durham and Leeds Cases

Parts of the cities of Durham and Leeds in the UK were evaluated to determine the positive effects of pedestrianization on noise pollution. Before the implementation of a pedestrianization scheme, the noise levels in the study area of Durham exceeded the acceptable limit of 68 dB(A) at that time. In Leeds, the noise levels have been reduced from 65-75 to 60-65 dB(A) after pedestrianization was implemented (Chiquetto, 1997).

3. **The Case of Green Walls**

The effect of green walls on noise pollution was also tested. A green wall with an area of 922m^2 (48m x 19.2m) was placed on an apartment building situated on a main road. Approximately 20 000 vehicles passed the building per day at an average speed of 50 km/h. The vehicles consisted out of 95% light vehicles and 5% heavy vehicles. The average noise level before the implementation of green walls was 63.77 dB(A). After the green wall was installed a reduction of approximately 4.3 dB(A) was recorded (Veisten *et al.*, 2012).

C.3 The Effect of Pedestrianization on Economic Factors

The economic effects of pedestrian schemes should not be considered in isolation. The following external factors should be evaluated in combination with the economic effects (Hass-Klau, 1993a):

1. Any trends locally and nationally;
2. Accessibility of the pedestrianized scheme by public transport or motor-vehicles;
3. Overall town planning strategy;
4. Design of the scheme;
5. Density of the nearby or surrounding population.

Through the implementation of pedestrian schemes the economic advantages thereof were identified in a number of cases as elaborated upon in this section. The following previous studies and cases have been consulted in the research on the effect of pedestrian zones on the economy:

1. Organisation for Economic Co-operation and Development (OECD) Study Case;
2. The Oxford and Cambridge Cases;
3. The Istanbul Case;
4. The Seville Case;
5. The Kajaani Case;
6. The Wolverhampton Case;
7. Rhodes and Katerini Cases;
8. Relationship between Urban Health and Economic Benefits.

Each study will now be described in more detail.

1. Organisation for Economic Co-operation and Development (OECD) Study Case

Research in 1989 concluded that pedestrianization improves the physical environment, in turn contributing to economic improvements in terms of retail turnover. It was noted that retailers in areas that underwent pedestrianization experienced a growth in sales. One hundred pedestrianized cities around the world were investigated. It was found that the turnover in 49% of these city centres increased and 25% remained constant. More than 60% increase in turnover was recorded in Austria, Scandinavia and Germany (Darko & Atuahene, 2015).

Research conducted on pedestrianization by Hall, Hass-Klau and Monheim confirmed the apparent obvious that the number of shoppers and turnover in an area are directly proportional to the number of pedestrians in the streets (Darko & Atuahene, 2015).

In pedestrianized areas of Belgium residents were provided with free public transport. This improved commerce and business in those areas and resulted in a growth in municipal revenue and a reduction in business tax rates (Darko & Atuahene, 2015).

Studies of Texas, USA concluded that office buildings with good pedestrian amenities have higher occupancy rates. This was confirmed in Toronto where it was found that buildings not situated on the pedestrian corridors have higher vacancy rates and get half the annual rent income (Darko & Atuahene, 2015).

In most cases it was found that pedestrianization increased land value, resulting in rent increases and increases in property tax assessments. It was found that increased sales at pedestrian corridors offset rent increases. Sales explosion in York, UK resulted into a 400% increase in rent (Soni & Soni, 2016).

Hass-Klaus reported that pedestrianized streets can result in a 20% to 40% increase in the amount of shoppers for retail services. A mean increase of 17% in retail turnover was calculated, although an increase in the range of 10% to 25% is suggested as an expected increase in retail turnover. A mean increase of 22% in retail rents was calculated. An increase in the range of 10% to 30% is suggested (Whitehead *et al*, 2006).

2. The Oxford and Cambridge Cases

In Oxford a small decline in trade for the city globally was noticed in the late 1990's. In the same period, an increase of 8.5% in pedestrians was however noticed for pedestrianized streets. This increase consequently resulted in increased trade. An increase of 9% in bus passengers was also recorded (Wallztrom, 2004).

Economic benefits were also observed in Cambridge. Less congestion resulted in time saving for public transport users and no significant loss of trade was recorded in the pedestrian area, with only an increase in the number noticed for pedestrians and tourists using the area. With the increased number of pedestrians it could only be derived that it resulted in an increase in trade (Wallztrom, 2004).

3. The Istanbul Case

A commercial survey was conducted within the area of the historic Peninsula of Istanbul which underwent pedestrianization. From the survey of respondents within that area 47% were retailers and the other 53% wholesalers (Öztaş & Akı, 2014).

A total of 50% of the respondents indicated that their collection and delivery activities were benefitted by the pedestrianization in the area. Within the retail sector, 51% of the survey respondents indicated that the pedestrianization scheme affected their business positively. Only 35% of the retailers disagreed. Amongst the wholesalers, 52% respondents agreed that the impact of pedestrianization on their business was positive while 38% of the wholesalers disagreed. From the survey respondents 53% confirmed that the pedestrianization caused an increase in street vendors. Many were however displeased with this situation (Öztaş & Akı, 2014).

4. The Seville Case

Seville has the largest city centre in Spain with an area of 394 hectare and a population of 702 355 inhabitants. During the period of 2006 to 2008 pedestrianization was implemented in the old city centre. Asuncion Street is 875m long of which 520m thereof has been pedestrianized as seen in Figure C10.

Figure C10: Asuncion Street, Seville, Spain (Sevillano, 2015)

Before the implementation of the pedestrianized scheme the streets were constantly congested with vehicles, retailers and pedestrians. In access of 8920 vehicles moved through the city centre daily and released 160 tonnes of CO per annum (Castillo-Manzano *et al*, 2014).

San Jacinto Street is 655m long with 210m of the street pedestrianized. Before pedestrianization 15000 vehicles used the street daily (Castillo-Manzano *et al*, 2014). San Jacinto Street was also known as the noisiest street in Seville.

After the implementation of the pedestrianized areas, a survey was conducted in 2009 to determine the impact of the pedestrianization. The survey was repeated in 2012 to determine the longer term effects.

The initial survey showed that 26.5% of respondents increased the frequency of visits to the zone post-pedestrianization in comparison to 33.5% responding to the new survey. From the initial survey respondents with retail interests, 47% indicated an increase in sales while 51% indicated an increase in the repeated survey. From the initial survey, 55% of the respondents indicated an increase of consumption from food and beverage establishments in comparison to 62% in the repeated survey (Castillo-Manzano *et al*, 2014).

It is interesting to note that these results were obtained despite the rapid decline in the Spanish economy during the 2011 to 2012 period (Castillo-Manzano *et al*, 2014).

5. The Kajaani Case

The main square and a portion of High Street in Kajaani, Finland were pedestrianized in 1996. The pedestrianization scheme was implemented in an effort to address congestion, air pollution, the migration of the population from the city centre and the urban decay caused by vacant properties. The city managed to remove 13000 vehicles per day from the main square. This resulted in a 52% improvement in retail business (Wallztrom, 2004). The main pedestrian square of Kajaani is illustrated in Figure C11.

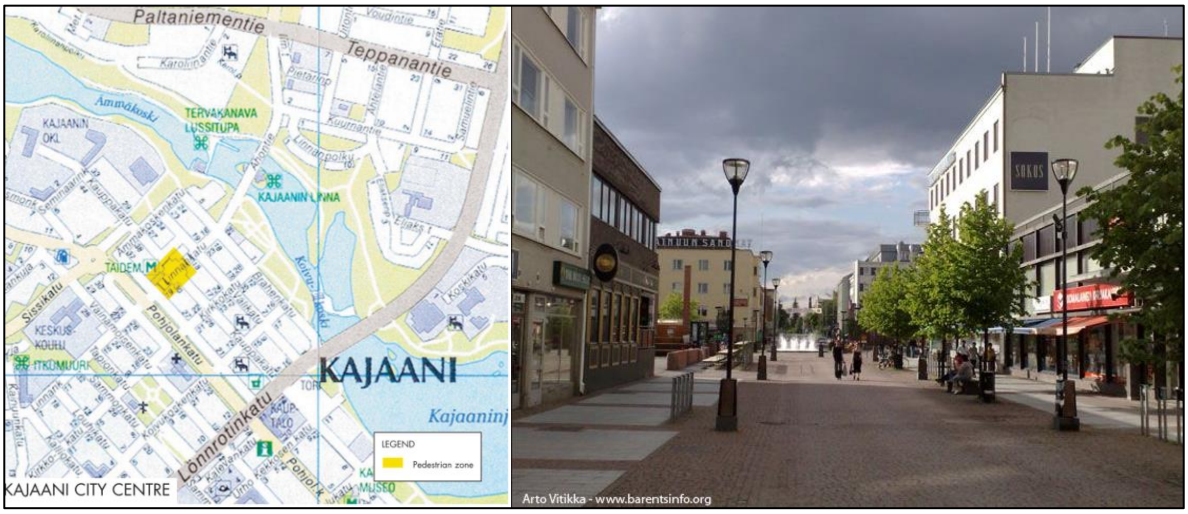

Figure C11: Kajaani, Finland pedestrian zone (Wallztrom, 2004)

6. The Wolverhampton Case

The pedestrianization of the central core roads of Wolverhampton, England in 1991 led to the removal of 8000 vehicles/day from the city centre. The main reasons for the pedestrianization scheme were the high congestion levels, worsening environmental conditions and the decline in economic activities. After the pedestrian scheme was implemented, the central core for investment became the pedestrianized streets. A 30% increase in the use of public transport was also noticed (Wallztrom, 2004). The pedestrianized streets of Wolverhampton can be seen in Figure C12.

Figure C12: Pedestrian zone in Wolverhampton, England (Wallztrom, 2004)

7. The Rhodes and Katerini Cases

In the case where Rhodes and Katerini were pedestrianized a reduction in fuel consumption and average delay per vehicle were recorded, positively affecting the local economy (Brebbia, 2000).

8. The Relationship between Urban Health and Economic Benefits

The overall "health" of urban areas should also be taken into account when the economic benefits for a CBD area are considered. A combination of environmental degradation, poorly maintained buildings and infrastructure, undermanaged street trading and transport as well as high crime levels have negative economic implications.

The economic chain reaction in urban cities can be described as:

Neglected environments (lack enhancements such as trees and gardens) → low environmental quality → city regarded as low priority by financial investors.

Cleaner and greener cities motivate happier, healthier and more productive habitants, international business and tourism and are more attractive to property developers. As an example, in Durban the price of property is strongly influenced by environmental factors. Higher prices are associated with a better condition of the surrounding environment and open spaces. Degraded open spaces are not only associated with lower prices, but also with crime. From this study it was concluded that people value public space more than private gardens since such areas are perceived as safer, more accessible and multifunctional (White et. al., 2017).

Noteworthy is that approximately 15.5 million people visited Durban in 2012. This resulted in a total expenditure of R6 132 million and contributed R10 500 million to the Gross Domestic Product (GDP) (White et. al., 2017).

In Cape Town the urban open spaces contribute to 18-43% of tourism revenues (White et. al., 2017). Figure C13 provides a breakdown of the type and location of activities generating tourist expenditure in Cape Town with the highest expenditure in business within the built environment. With a large percentage of business activities within the CBD areas, it can be concluded that green cities through green pedestrian zones would be more conducive to business, tourism and shopping.

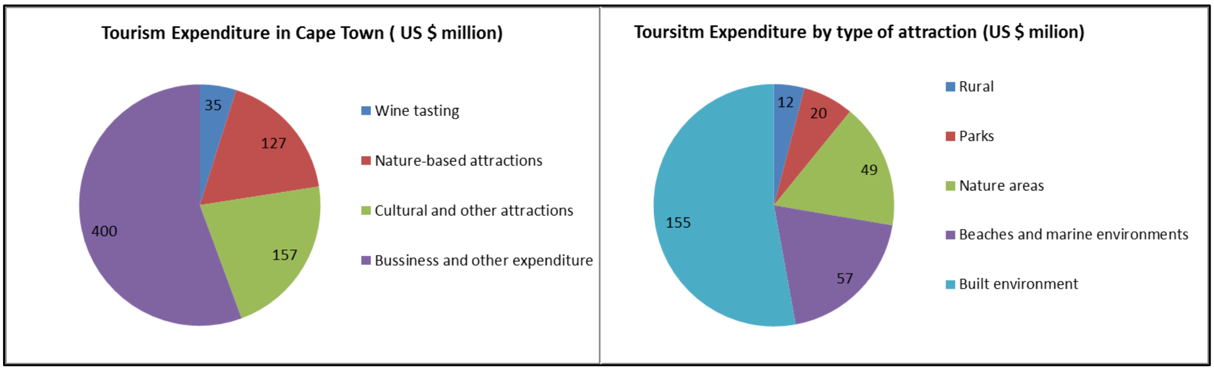

Figure C13: Tourism expenditure in Cape Town by activity (left) and by location (right) (White et. al., 2017)

C.4 The Effect of Pedestrianization on Social Benefits

Improved air quality, greater social cohesion, relaxation, stress reduction and enhanced physical activities are all ways in which environmental quality, or green spaces contribute to health and well-being (White et. al., 2017).

On the other hand, poor air quality, overcrowding, high traffic volumes and the absence of safe open public spaces all lead to socio-cultural changes, mental illness or psychiatric disorders from poor living conditions (White et. al., 2017).

In Spain the physical and mental health of people with an increased exposure to green spaces improved irrespective of gender or socioeconomic status. In Canada open green spaces reduced mortality, especially from respiratory diseases (White et. al., 2017). Not only the presence of green spaces but also the conditions of these open green spaces are of high importance.

In Cape Town many neighbourhood parks still exist, but due to the unsafe nature (caused by various factors not in the scope of this thesis), people prefer not to use them. As a possible solution to this problem the City of Cape Town suggested to turn small parks into “smart” parks (White et. al., 2017). These smart parks will contain amenities such as small businesses and restaurants. The aim is to encourage the use of a well-maintained environment, deter criminal activities and create the opportunity for people to enjoy the public open space. This is also the aim of what to achieve by creating green pedestrian zones. The only difference is that existing busy urban streets with existing businesses and restaurants will be transformed into a “smart” park, instead of creating a new smart park form inception.

Figure C14 illustrates the factors forming green urban development. These factors can be applied in existing areas or used as guidelines when new developments are started. In order for a city to move in a positive environmental direction, urban growth and city structure should be managed. This can be achieved by avoiding the loss in natural open spaces. Open spaces will become more valuable as the city grows and sufficient open spaces should be preserved in each part of a city. In addition, proper waste and storm water management should be implemented and natural resources must be protected (White et. al., 2017).

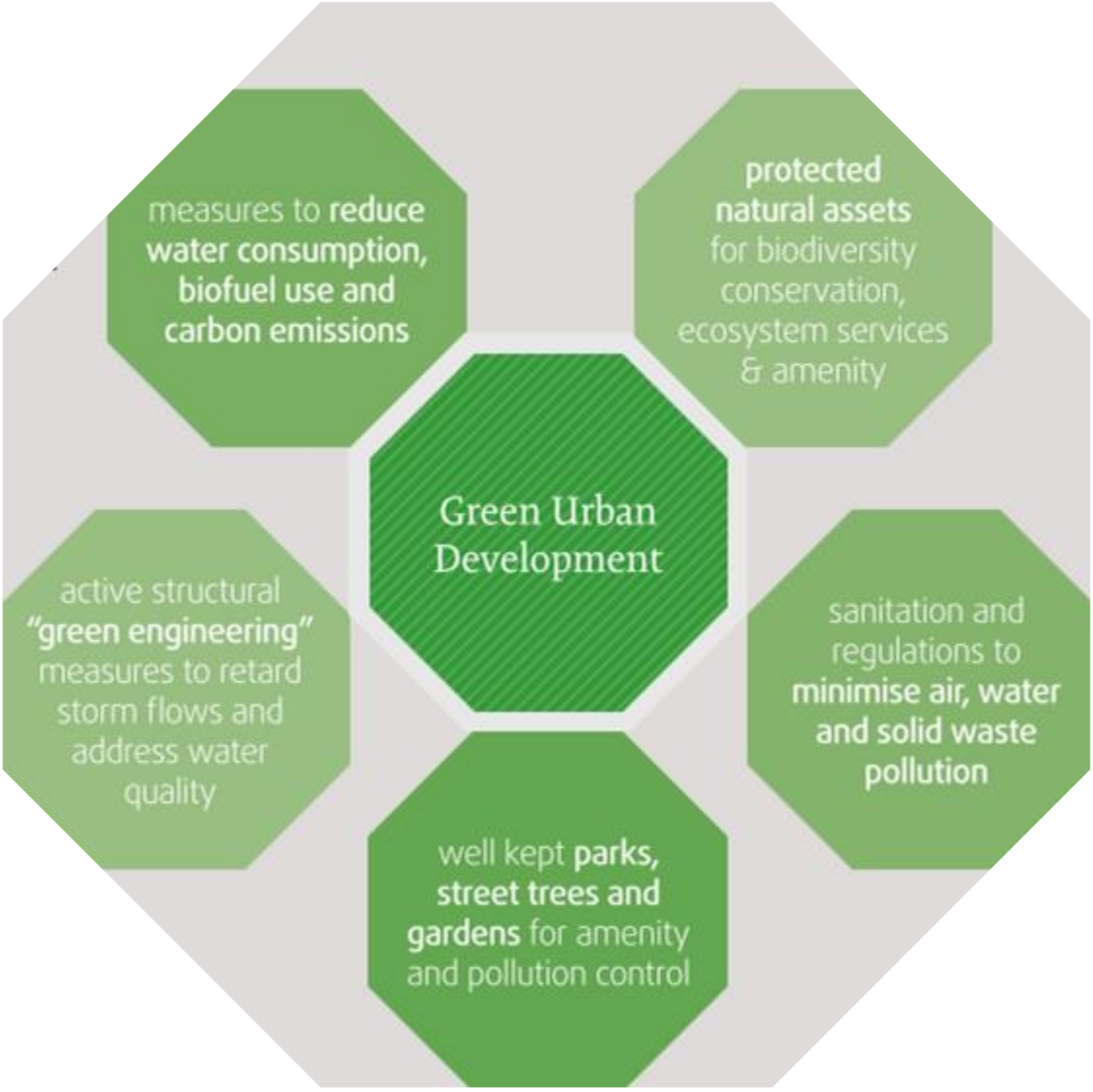

Figure C14: Considerations for green development (White et. al., 2017)

The following previous studies are reviewed:

1. Cambridge;
2. Kajaani;
3. Wolverhampton;
4. Ghent;
5. Seoul;
6. Seville;
7. Istanbul;
8. Katerini.

The social benefits associated with each case study are described in the following sections.

1. The Cambridge Case

In the pedestrianized streets of Cambridge pedestrians and cyclists reported that they feel safer and that they benefitted from the cleaner and quieter city environment (Wallztrom, 2004).

2. The Kajaani Case

Apart from the reported economic benefits of pedestrianization in Kajaani, Finland, residents stated that they feel more comfortable and safer in this area than before the main square was pedestrianized. Before the pedestrian scheme was implemented; 60% residents perceived their "quality of life" to be good. After implementation 80% of residents reported a good quality of life; an increase of 20%. The perception of the city to be "aesthetically beautiful" also increased with 8% from 47% to 55%.These factors contributed to an increase of pedestrian visits to the main city centre square (Wallztrom, 2004).

3. The Wolverhampton Case

In the pedestrianized street of Wolverhampton, England, the perception of a safer, cleaner, more accessible and more attractive city was created (Wallztrom, 2004).

4. The Ghent Case

The city centre of Ghent, Belgium, was closed for private cars in 1997. This was done in order to create a more liveable city and to prioritise cyclists, pedestrians and public transport. After the pedestrian scheme was put in place there was an increase of 3-5% in public transport users. Accident levels were reduced by 30%. The city culture was also revitalized. The pedestrian streets made it possible to hold events in the city streets such as open air art and music festivals and improved the shopping atmosphere (Wallztrom, 2004). Figure C15 indicates the pedestrianized streets of Ghent.

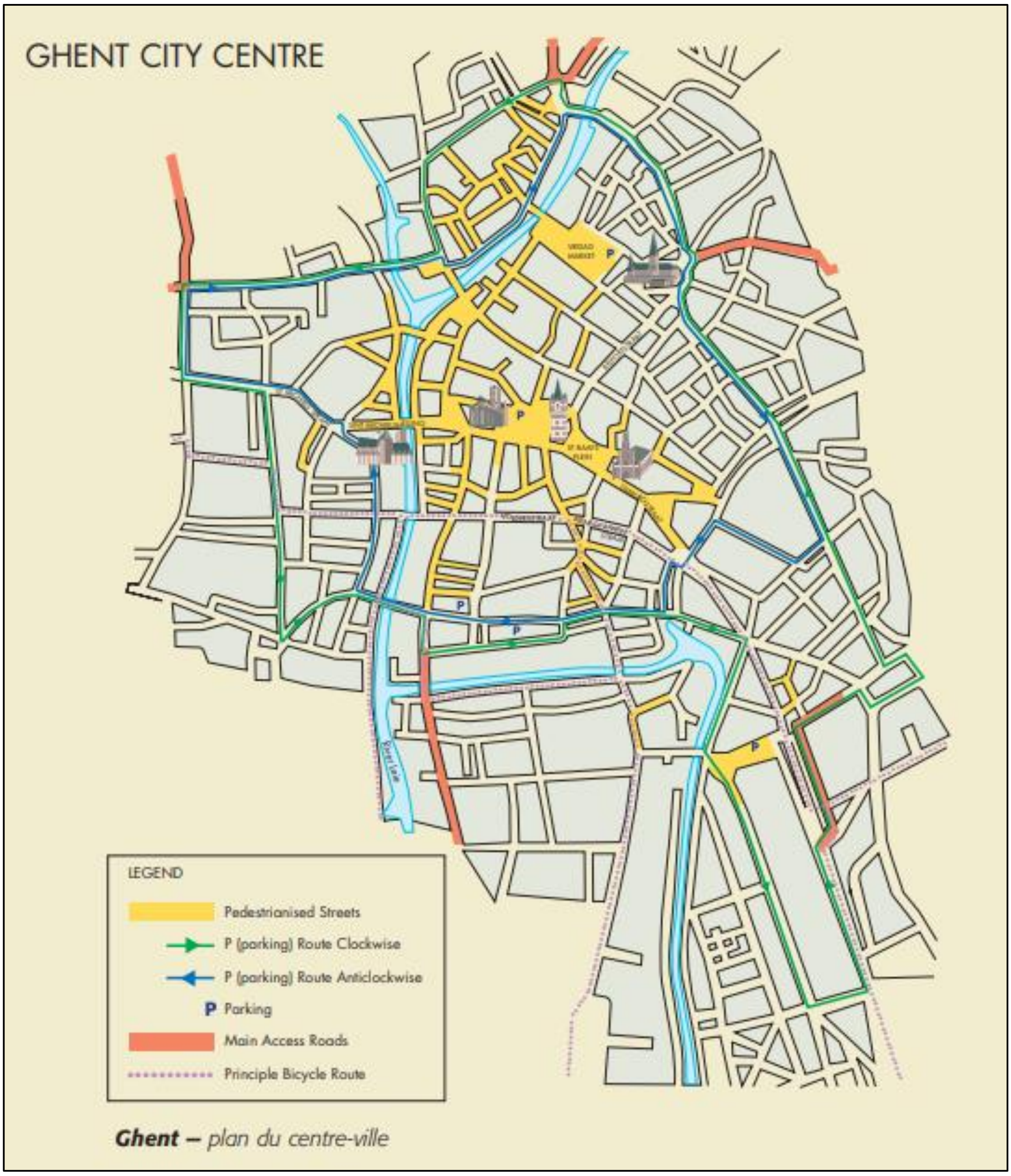

Figure C15: Pedestrianized streets of Ghent (Wallztrom, 2004)

5. The Seoul Case

In Seoul, South Korea, a study was conducted to determine whether an improved physical street environment created active streets and higher perceived satisfaction (Jung *et al.*, 2017). The pedestrian perspective of the area was obtained via surveys where pedestrians were requested to rate and weigh their level of satisfaction. The rating options were as follows:

5 = very satisfied
4 = satisfied
3 = neutral
2 = dissatisfied
1 = very dissatisfied

The first hypothesis tested in this study was that with physical street improvements the level of pedestrian satisfactory would also increase. Physical improvements include safety, cleanliness, scenery and convenience. The first survey was conducted in 2009. A second survey was conducted in 2012.

In 2009 the average rating for pedestrian satisfaction in streets where no physical improvements were done was 3.256. This decreased to 3.092 in the 2012 survey. In contrast to the finding above, the streets where design alterations were implemented to improve physical appearance the average satisfaction rating increased from 3.213 to 3.355 from 2009 to 2012 (Jung *et al.*, 2017).

A second hypothesis was also tested. This hypothesis was not focused on pedestrian satisfaction, but on the pedestrian volume and how to increase pedestrian volume by changing the streetscape. The streetscape was changed by adding features such as streetlights, trees, benches and other street furniture. In 2009 before changes were brought about, the pedestrian volumes were estimated as 7249.6 persons. After the streetscape changes were implemented a pedestrian volume of 7908.6 persons were estimated in 2012 (Jung *et al.*, 2017).

6. The Seville Case

In the city of Seville, Spain, surveys were conducted among pedestrians and residents to determine the city atmosphere before and after pedestrianization. Over 90% of the respondents to the surveys indicated that the area had a livelier atmosphere after the installation of pedestrianization. The only negative aspects citizens highlighted were the way in which the road works were carried out and the disruption it caused. Pre-pedestrianization conflicts were soon changed to become more welcoming of pedestrianization (Castillo-Manzano *et al.*, 2014).

7. The Istanbul Case

Surveys within the business, residential and student district of the Historic Peninsula of Istanbul revealed the following benefits form creating pedestrian streets within the historical peninsula (Öztaş & Akı, 2014):

1. 68% increase in street safety;
2. 58% increased visual quality;
3. 56% increase in attraction to historical buildings;
4. 52% increase in walkability;
5. Overall 80% satisfaction rate.

8. The Katerini Case

Accidents in the greater street network of Katerini were reduced by 44% as a result of pedestrianization. An overall improvement in the level of safety along the road network was noted. It was further reported that the quality of life in central areas of Katerini also improved (Brebbia, 2000).

C.5 The Impact of Pedestrianization on the Surrounding Traffic

80% of the European population live in cities. It is therefore of importance to improve the urban liveability. It is however a difficult task since the dependency on cars is still too high and the use of cars is still on the increase. It is found that 50% of all journeys in urban areas are less than 5km long and 33% less than 3km (Wallztrom, 2004). The environmental, social and economic challenges that are caused by increasing traffic are illustrated in Figure C16.

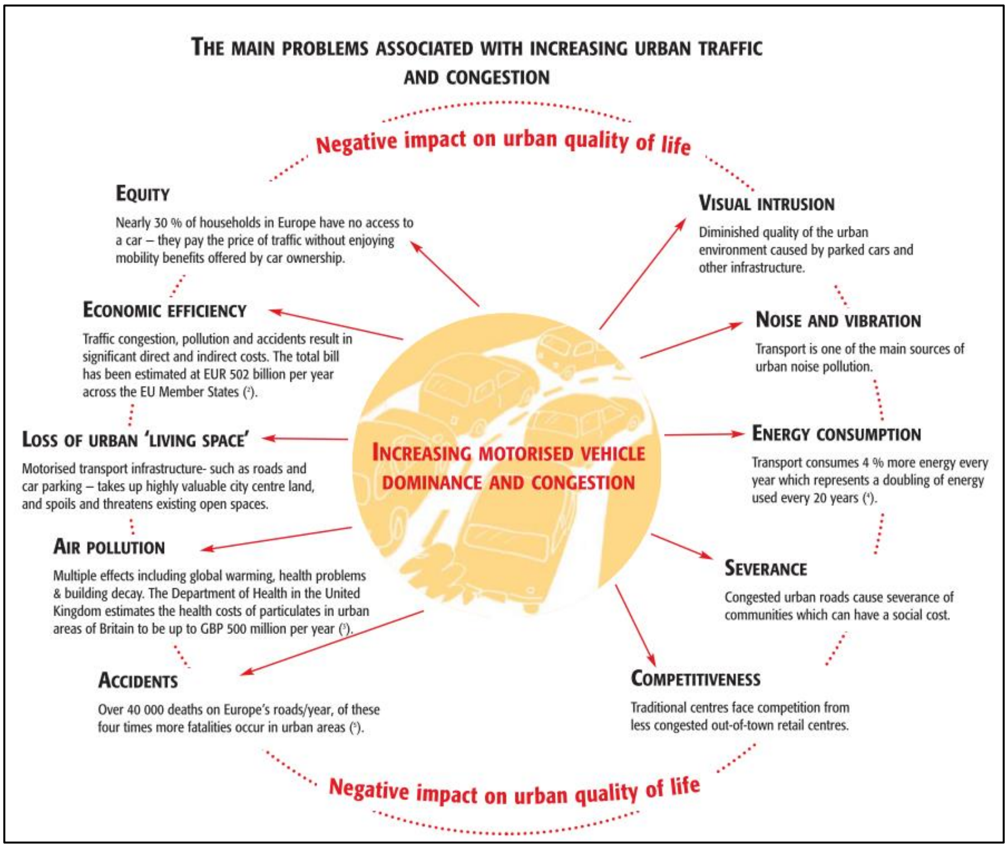

Figure C16: Problems associated with increasing congestion (Wallztrom, 2004)

In the city of Chester the closure of some of the central area roads increased the overall traffic circulation, resulting in reduced congestion levels, reduced travel times and lower fuel consumption. This is explained by the "Braess's Paradox", where user equilibrium will occur. User equilibrium indicates that each user will minimize their own travel time and associated travel costs (Sheffi, 1985).

Wardrop's first principle states that under equilibrium conditions traffic arranges itself in congested networks in such a way that all of the used routes within a network between any origin and destination have equal and minimum costs. All of the unused routes will have greater costs. Wardrop's principles are frequently explained by Braess's Paradox where under certain conditions, the addition of capacity to a road network can actually worsen the network operations. It is due to the selfish nature of drivers always seeking the routes with the minimum associated time and cost (de Dios Ortuzar *et al*, 2012). It can therefore be concluded that it is not always necessary to add capacity to a road network to relief congestion. Users will always determine the most cost effective route whatever the capacity. It can also be concluded that in the case where capacity is removed by pedestrian schemes, the traffic that was on the routes that are now closed, will spontaneously re-arrange itself in the surrounding network.

Although there was a slight increase in travel distance in the total network of Chester, traffic flowed more freely over the total network after the pedestrianization scheme was implemented. The average travel speed increased with 3.1%, the average travel time decreased with 2.75% and the fuel usage decreased with 2.25%. A decreased consumption of fuel provides an economic benefit. Figure C17 provides a graphical representation of these findings (Chiquetto, 1997).

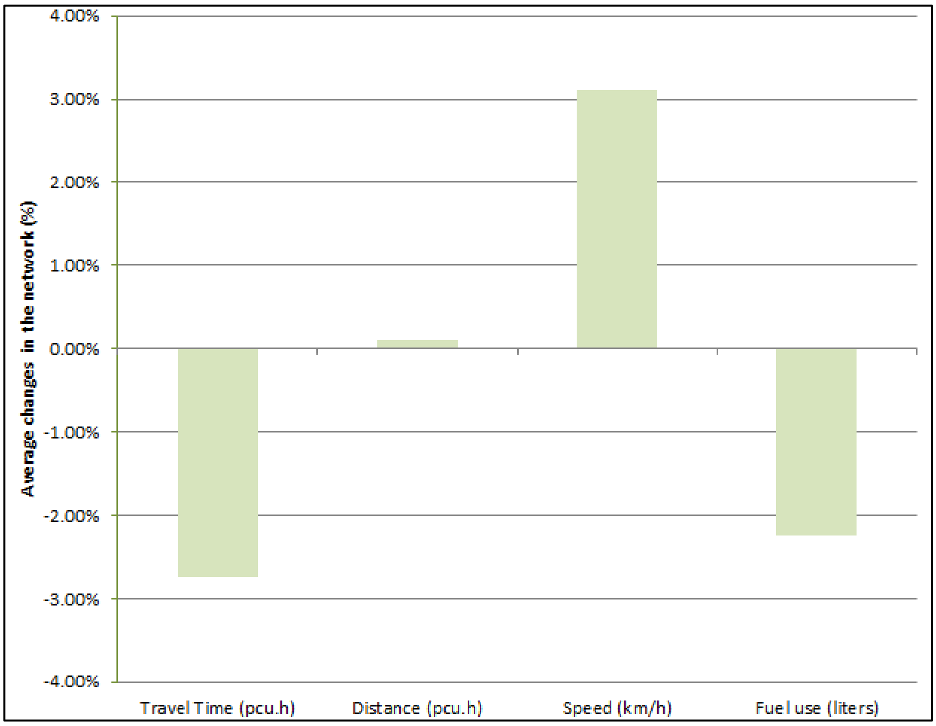

Figure C17: Percentage changes in traffic indicators due to pedestrianization as adapted from source (Chiquetto, 1997)

A study conducted by Wallztrom investigated whether the reclaiming of city streets for pedestrian use would result in chaos or an improved quality of life. This study highlighted that road traffic affects the quality of the environment and the quality of life in town and city centres within these environments. Traditionally the approach to solve congestion would be to provide additional road space. This solution was however proven to not be as effective as anticipated, since traffic jams in areas where extra traffic lanes were provided, worsened. A lack of space in which to expand could also impose new problems. A new approach to solve congestion in cities would be to start using the existing road capacity more efficiently. The aim should be to create new attractive public spaces in areas that were once congested and to encourage the use of alternative travel modes (Wallztrom, 2004). The experience with this new approach was that the traffic problems following the implementation of a scheme were less severe than predicted, that the traffic problems existing after implementation "evaporated"[2] and that the urban environment became more liveable.

After the implementation of a scheme, there is an adjustment period. In this adjustment period, the drivers previously found in the vicinity, changes their travel behaviour resulting in the traffic problems eventually evaporating. This period is also known as the settling period and includes short term activities where drivers cram initially but later start to search for alternative routes. In the medium term drivers start to develop flexible trip planning, change transport mode, review trip

[2] The terminology of **"traffic evaporation"** is used for the phenomenon that resulted from strategic removal of road space previously dedicated to motor vehicles (OneStreet, 2018)

planning and combine trips. In the long term drivers may switch locations for activities and workplace or even homes. This seldom occurs. The cycle of "settling" can be seen graphically in Figure C18.

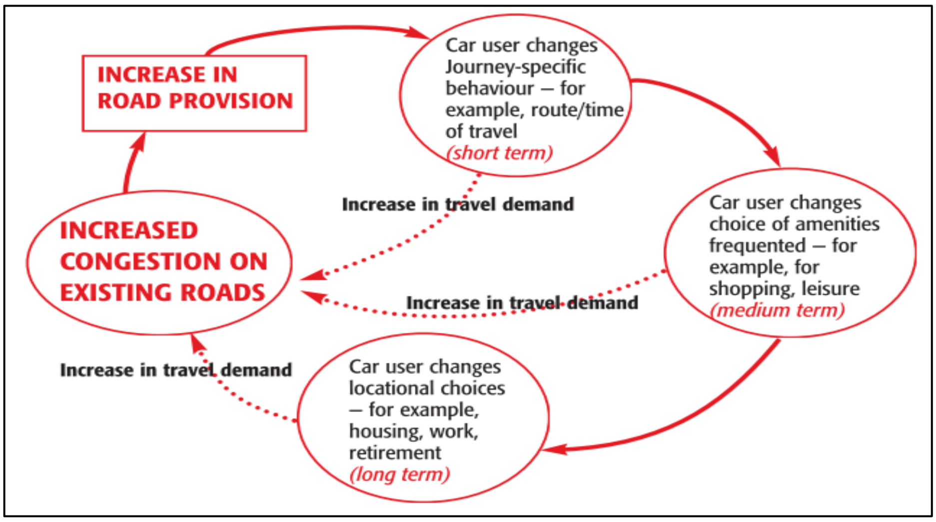

Figure C18: Cycle of traffic settling (Wallztrom, 2004)

In the case where the historic city centre of Nuremburg was pedestrianized there was a 25% reduction in traffic flow through the historic centre. There was however a recorded 19% increase in traffic on the surrounding streets. This does indicate that there was still an overall reduction in traffic of 6% (Wallztrom, 2004).

It was further noted in the city of Cambridge that there was a traffic reduction of 80% on the closed routes with no traffic increase on the neighbouring routes (Wallztrom, 2004).

In Kajaani, traffic evaporated where a daily number of 13000 vehicles were removed from the main square. No additional traffic was recorded on the surrounding network (Wallztrom, 2004).

The same trend was noticed in Wolverhampton where traffic evaporation caused a decrease of 14% in traffic within the city core and an overall decrease of 1% in traffic on the surrounding network. In Oxford the pedestrianized streets resulted in traffic flows that decreased by 20% in inner cordon and 1.13% on outer cordon (Wallztrom, 2004).

In the case where Rhodes and Katerini were pedestrianized a reduction of road accidents was observed in this area. In order to improve the level of safety over the greater network additional measures such as traffic signal interventions, junction redesign, proper signage and revised road super elevation (vertical and horizontal alignment) should be considered. In both of these cities the implementation of an on-street parking policy and parking stations near the pedestrian zone opened up space at intersections, thus increasing the capacity of junctions by 14-15% (Brebbia, 2000).

C.6 The Effect of Green Engineering Technologies

The green engineering technologies researched, include mainly green roofs and the effect of green roofs on the air quality within the surrounds of green roofs. Green walls and trees are also included in the research.

The most significant benefits associated with green roofs and green facades and walls are described in the following section. The benefits addressed include the following:

1. Noise Pollution;
2. Economic Benefits;
3. Improved Air Quality;
4. Other Benefits.

Each benefit will now be elaborated upon.

C.6.1 Noise Pollution

Green roofs and walls can provide some decrease in noise pollution. In Melbourne a study showed that green roofs can lead to a reduction of 10 dB in noise levels. In Singapore green walls were tested and the results indicated the same outcome (GreenWall_Australia, 2014). For additional information of how green walls reduce noise pollution refer to paragraph C.2.

C.6.2 Economic Benefits

In Canada it was found that the property value of buildings with green roofs increased with 11% and buildings with views over green roofs have a 4.5% increase in property value. Various studies done on the economic effect of green walls or roofs proved that green roofs and walls are beneficial for property value (Veisten *et al.*, 2012). Some of the results include:

- 10.5% increase in property value in Toronto;
- 3.9% increase in property value in Québec (Canada);
- 1.4% increase in land price in Tokyo;
- 2.7% increase in land price in Kitakyushu;
- Houses in New York with a green roof have 16.2% higher prices.

Furthermore, green roofs and walls can reduce the costs associated with heating and cooling of buildings (GreenWall_Australia, 2014).

C.6.3 Improved Air Quality

In the narrow streets of city centres, green walls and roofs provide improvement in the urban air quality. With an increased area covered in vegetation more pollutants will be disposed of. In London it was found that vegetation (in the form of green walls and roofs) resulted in a decrease of 23% - 60% in Particulate Matter and a decrease of 15% - 40% in nitrogen dioxide (GreenWall_Australia, 2014). In this section the following three case studies are included:

1. The case of Chicago;
2. The case of Toronto;
3. The case of Hong Kong.

C.6.3.1 The case of Chicago

In Chicago a study was conducted on the removal of air pollution by installing green roofs. It was found that 1675kg of air pollutants was removed by 19.8ha of green roofs. This was over a period of one year. O_3 made out 52% of the total weight, SO_2 7%, NO_2 27% and PM_{10} 14%. It was determined that one hectare of green roof will remove 85kg of air pollutants per year (Yang *et al.*, 2008).

The study consisted out of 71 green roofs totalling 19.8ha. 4.15% of these green roofs are on residential buildings, 81.97% on commercial buildings and 13.83% on office buildings. The green roofs consisted out of 63% short grass and low growing plants, 11% trees, 14% herbaceous plants and 12% hard surfaces. Table C6 provides the removal rate of air pollution by the different vegetation type on the green roofs for a period of one year (August 2006 to July 2007) (Yang *et al.*, 2008).

Table C6: Annual removal rate of air pollutants per canopy cover by different vegetation types in Chicago (Yang *et al.*, 2018)

Type of Vegetation	$SO_2(gm^{-2}yr^{-1})$	$NO_2(gm^{-2}yr^{-1})$	$PM_{10}(gm^{-2}yr^{-1})$	$O_3(gm^{-2}yr^{-1})$	Total $(gm^{-2}yr^{-1})$
Short grass	0.65	2.33	1.12	4.49	8.59
Tall herbaceous plants	0.83	2.94	1.52	5.81	11.10
Deciduous trees	1.01	3.57	2.16	7.17	13.91

Observations made during the study showed that the highest concentration of pollutant was removed during the summer month of May. This was when the plants were fully covered in leaves. Similarly, the lowest concentration removed was during February when the vegetation was covered in snow. It can therefore be concluded that the removal of air pollutants are affected by weather conditions, plant growth and concentration of air pollution present.

It was further determined that the annual removal of air pollution per hectare of tree canopy cover in Chicago was 97kg. In Toronto the rate was 69 kg per ha and 77kg per ha for Washington. Table C7 provides the minimum and maximum average monthly deposition velocities for different types of vegetation (Yang *et al.*, 2018).

Table C7: Deposition velocities of pollutants over different vegetation types (Yang *et al.*, 2018)

Type of vegetation	$SO_2(cms^{-1})$	$NO_2(cms^{-1})$	$PM_{10}(cms^{-1})$	$O_3(cms^{-1})$
Short grass	0.04 (0.005) 0.39 (0.006)	0.01 (0.001) 0.39 (0.006)	0.10 (0.005) 0.19 (0.003)	0.01 (0.001) 0.42 (0.007)
Tall herbaceous plants	0.04 (0.006) 0.48 (0.007)	0.01 (0.001) 0.49 (0.007)	0.10 (0.006) 0.25 (0.004)	0.01 (0.001) 0.65 (0.008)
Deciduous plants	0.05 (0.006) 0.5 (0.007)	0.01 (0.001) 0.58 (0.008)	0.13 (0.008) 0.36 (0.006)	0.01 (0.001) 0.65 (0.008)
NOTE: The minimum and maximum monthly average deposition velocities were shown here. The numbers inside the parenthesis were standard errors				

C.6.3.2 The case of Toronto

In this study the effects of green walls and green roofs were investigated on air pollution in the urban area of Toronto. Different quantities of trees and combinations of vegetation were researched. The Urban Forest Effects (UFORE) model was applied to model the effects. The model included NO_2, CO, PM_{10}, SO_2 and O_3. The hourly pollution removal rates are included as well as the economic value of removing these pollutants (Currie & Bass, 2008).

Different levels of natural vegetation, achieved by manipulating the amount of grass, shrub and tree cover were tested. The following seven scenarios were created and compared (Currie & Bass, 2008):

1. BASELINE: pollution reduction provided by the existing trees and shrubs.
2. GREEN WALLS: pollution reduction provided when the existing trees and shrubs are removed and vertical green walls were installed (3m from residential area)
3. NO BIG TREES: the effect on air pollution was determined when all trees with a diameter of 22cm or greater were removed.
4. NO TREES: the effect on air pollution was determined when all the trees were removed and where the existing shrubs were incorporated with green roofs.
5. TREES OFF BUILDINGS: shade providing trees for buildings (3-5m form buildings) were removed and the effect hereof on air pollutant reduction was determined.
6. LOW TREES: the effect on air pollution reduction was determined when all trees and shrubs were incorporated with green roofs.
7. GREEN ROOFS: the effect on air pollution reduction was determined when all trees and shrubs were incorporated with grass on green roofs

The results for each air pollutant for each scenario can be seen in Figure C19 to Figure C22.

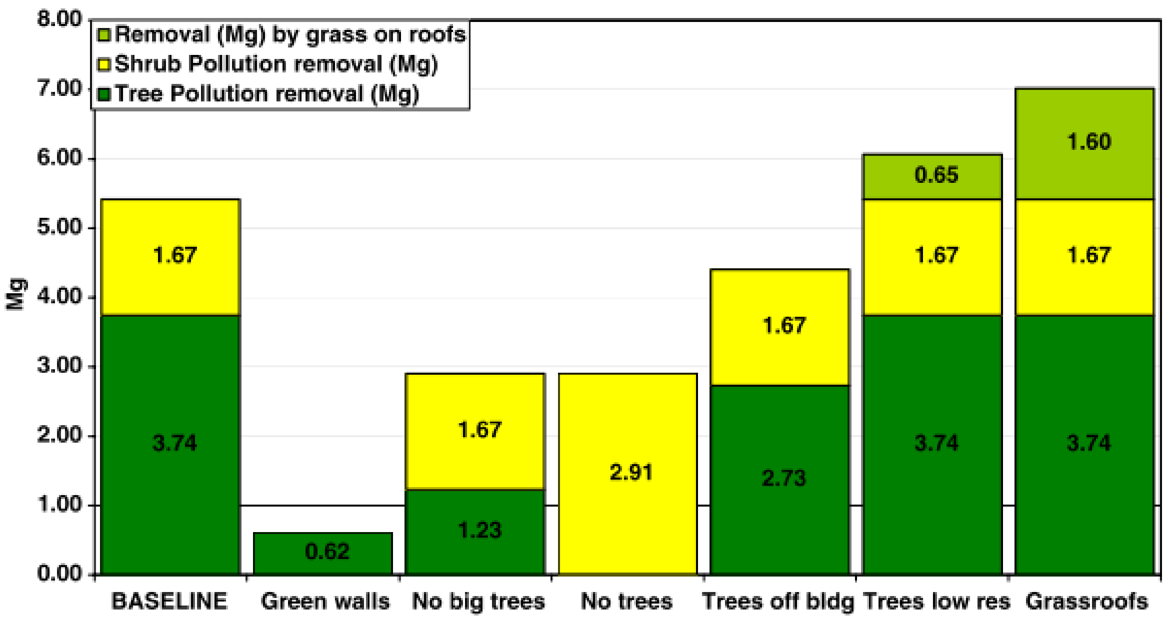

Figure C19: Total NO_2 removal (Mg) by trees, shrubs and grass per annum (Currie & Bass, 2008)

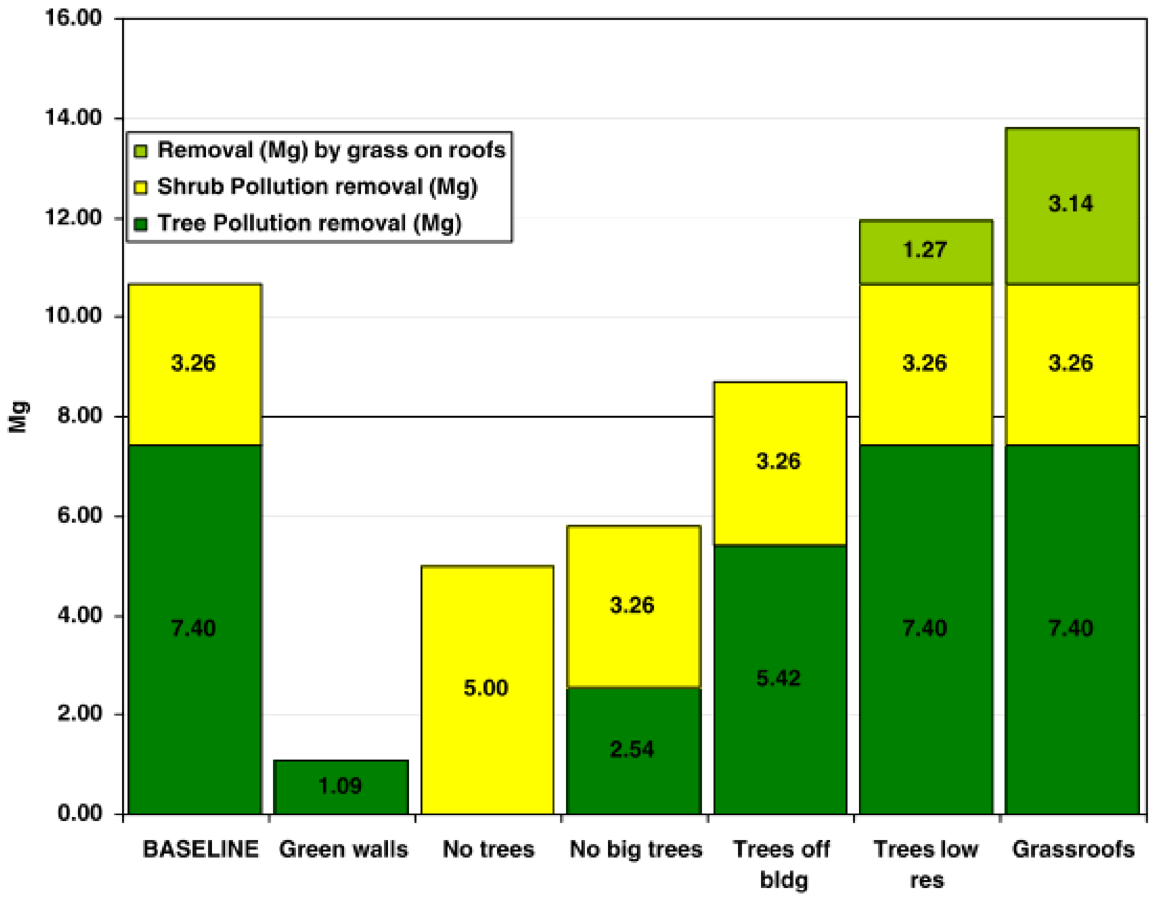

Figure C20: Total O_3 removal (Mg) by trees, shrubs and grass per annum (Currie & Bass, 2008)

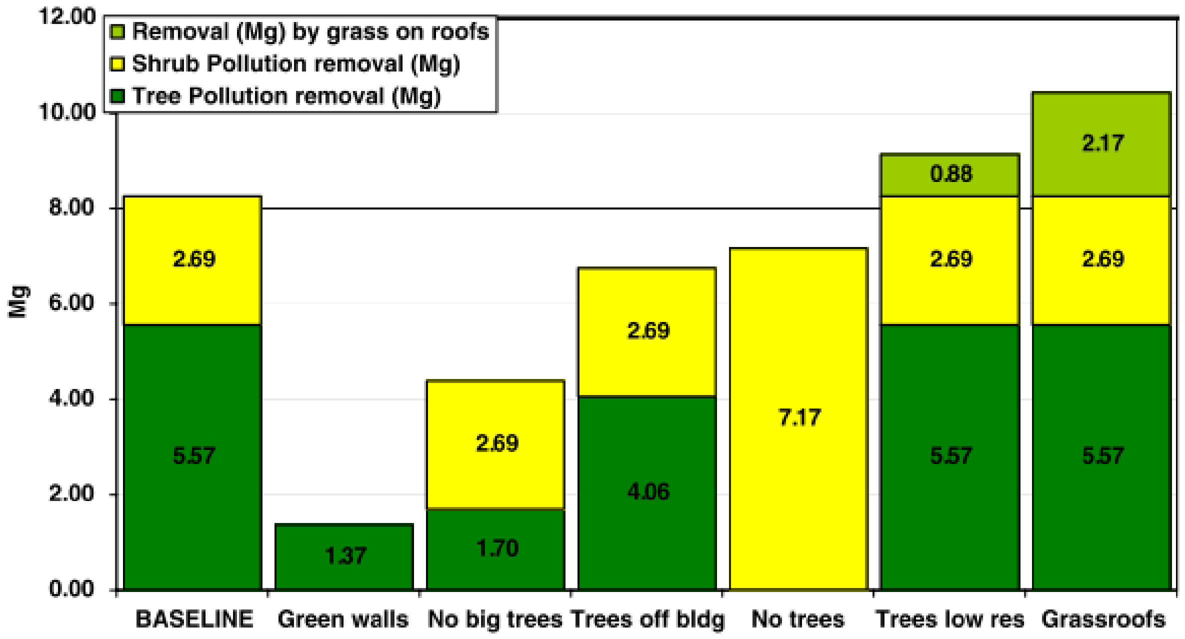

Figure C21: Total PM_{10} removal (Mg) by trees, shrubs and grass per annum (Currie & Bass, 2008)

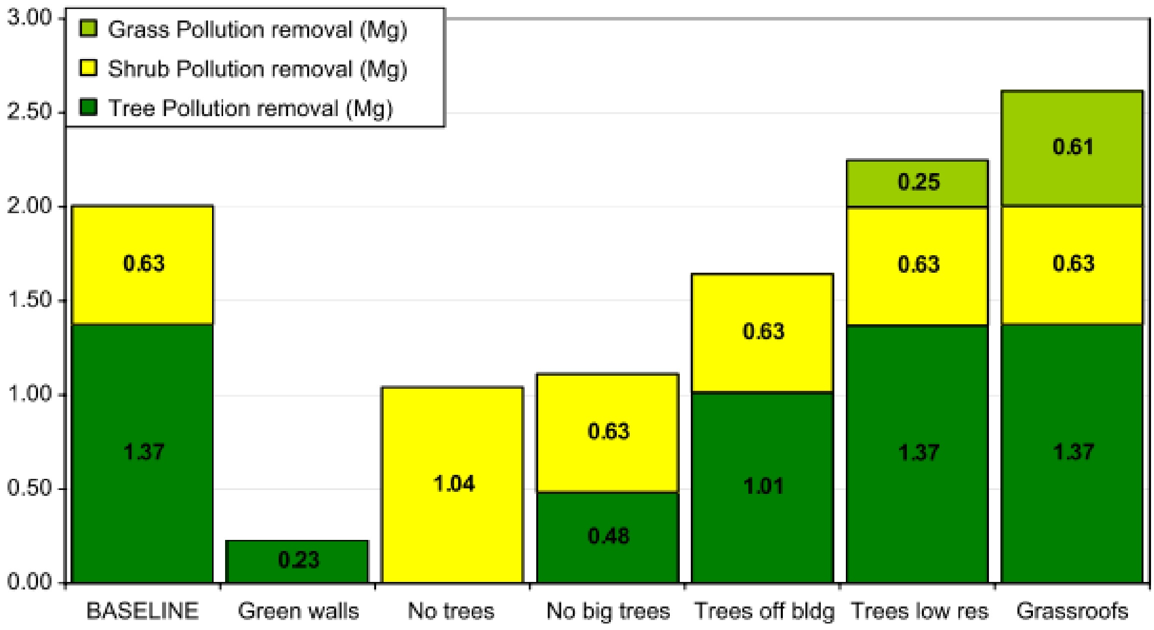

Figure C22: Total SO_2 removal (Mg) by trees, shrubs and grass per annum (Currie & Bass, 2008)

From the study it was concluded that by adding trees and shrubs with grass on green roofs the effect on air pollution mitigation improves. It was also determined that with an increase of 10-20% in the surface areas of green roofs will contribute to environmental, financial and social health of citizens (Currie & Bass, 2008).

Interpreting the obtained results it was concluded that trees contributed the most to reduce the amount of air pollutants in the Midtown of Toronto. Green roofs and walls with shrubs also make a noteworthy difference and even equal the performance of trees in some cases.

The pre-feasibility model constructed in this thesis is interested in the effect of green walls, green roofs and trees on the air quality of a city area. The data obtained from this particular study in Toronto is analysed and interpreted to be used in the pre-feasibility model in Chapter 7.

In this study 72 plots were analysed. A typical circular plot can be seen in Figure C23.

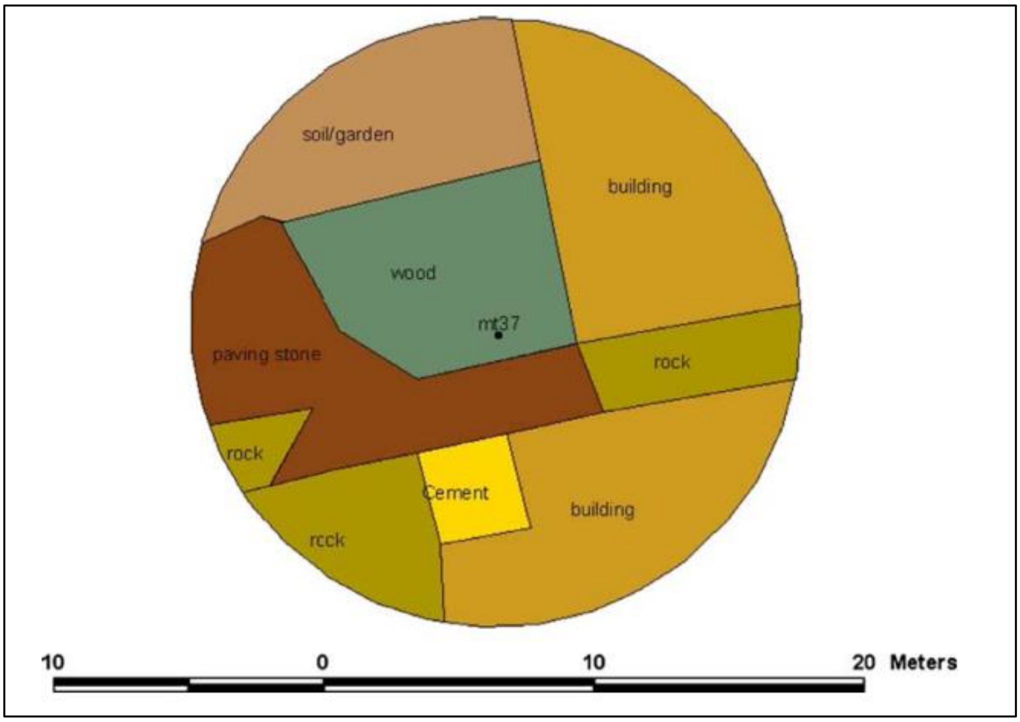

Figure C23: Sample circular plot (Currie & Bass, 2008)

Each plot is approximately 400m^2 (circular plot with radius of 11.287m). The area of buildings in a typical plot is measured to be equal to approximately 130m^2. Likewise, the area of tree cover in a typical plot is equal to 65m^2 (Currie & Bass, 2008). Green roofs made up 20% of the roofs in the Midtown allocated on high residential, institutional and commercial buildings [20% = sum of total area of eligible roof surface]. Therefore, the area of green roofs in a typical plot is equal to 26m^2. The area of green walls present in the study area is not specified. Therefore, only the effect of the presence of green walls in a built up area of 130m^2 can be measured. Table C8 provides a summary of the effects of green walls, green roofs and trees on the reduction in air pollutants within an area. The data as presented in Table C8 is obtained from analysing the results presented in Figure C19 to Figure C22.

Table C8: Summary of air pollutant removal for the case study of Toronto

Removal of air pollutants under various conditions							
Pollutant	Base Conditions	Green walls (per 130m^2 of built up area)		Green roofs (scrubs, trees & grass) per 26m^2		Trees per 62m^2	
	Mg	Mg	% increase in pollutant removal	Mg	% increase in pollutant removal	Mg	% increase in pollutant removal
NO_2	5.41	0.62	11.46%	1.6	30%	2.5	46%
O_3	10.66	1.09	10.23%	3.14	29%	5.66	53%
PM_{10}	8.26	1.37	16.59%	2.17	26%	1.09	13%
SO_2	2	0.23	11.50%	0.61	31%	0.96	48%

C.6.3.3 The case of Hong Kong

A study conducted in Hong Kong measured the absorption of CO_2 before and after the implementation of green roofs. The area of the green roof used in this study is 218.3m^2 (18.5m x 11.8m) and the leaves on the green roof is estimated to have an area of 657m^2. An absorption rate of 0.03m/min and environmental CO_2 concentration of 700 mg/m^3 was used in the study. It was found that the green roof absorbed approximately 13.8g of CO_2 in a minute. The overall reduction on CO_2 within the area of the green roof was approximately 1.85% (Li *et al.*, 2010).

C.6.4. Other Benefits

Green engineering technologies can contribute to lessen the urban heat island effect. The pollutants are directly captured by the vegetation which also contributes to the minimization of the urban heat island effect and the production of smog. In the Greater Melbourne area the vegetation of green roofs and walls are used to cool urban areas. This is known as green infrastructure.

Green engineering technologies can also reduce the storm water run-off in urban areas due to green roofs absorbing excess water. Green roofs also contribute in improving the quality of the run-off water (GreenWall_Australia, 2014).

C.7 The Effect of Green Spaces on the Environment

A study on the ecological outcomes of civic and expert-led urban greening projects using indigenous plant species in Cape Town, South Africa was conducted. This study investigated the outcome of plant greening interventions in the city of Cape Town. The study explores how society forms the urban ecology and how public green space and gardens form part of the urban fabric. In this study a linkage is created between the responsibility of the civil society to achieve conservation goals and the quality of life associated with these ecological outcomes (Anderson et. al., 2014).

Urban green spaces such as parks and urban forests play a vital role in sustaining an urban and social-ecology. In the 2460 km^2 city area of Cape Town there is 3350 plant species with abundance in Fynbos. Due to urban growth, Cape Town has the highest concentration of threatened plant species per area in the world, with only 14% of the original area left for vegetation and 11 of the 19 vegetation types in the city are threatened (Anderson et. al., 2014).

Form this it can be taken that attention should be given to the existence of the natural flora in urban planning. Solutions can include the rehabilitation of existing vegetated areas or creating new vegetation areas. The study concluded that by intervening in existing green spaces by the removal of waste and intruder plants, the biodiversity of the endemic plant and insect species, especially pollinating species such as bees can be promoted. Furthermore, the creation of new green spaces will also contribute to the conservation and promotion of the urban ecology and biodiversity. This is however only attainable when the civil society, residents, civic associations, urban planners, and other parties collaborate (Anderson et. al., 2014).

A study was conducted in Port Alfred and Fort Beaufort. In this study the perceptions of residents in Port Alfred and Fort Beaufort on public green spaces were researched (Shackleton & Blair, 2013). Residents in both towns indicated that they would like to have more public green spaces in their town. From the results it was concluded that the following factors play a significant role in whether residents will make use of a public green space:

1. Distance to public green space;
2. Whether the public green space is well maintained;
3. Whether the public green space is safe[3];
4. Whether the public green space has good facilities, is spacious and has sufficient vegetation.

The residents further indicated that the benefits they gained from using public green space are relaxation, recreation, employment opportunities and environmental benefits. Another important conclusion drawn from this study is that it is important to capture the needs of the people who will be using the space in order for the space to be optimally utilized (Shackleton & Blair, 2013).

[3] 41% of residents in Fort Beaufort and 49% in Port Alfred indicated that they felt unsafe when using public green spaces

APPENDIX D: SEMI-STRUCTURED INTERVIEWS

Semi-structured interviews were conducted with industry professionals. The interviews consisted primarily of critique on the developed pre-feasibility model. Part 1 of the pre-feasibility model, the Location Determination Checklist, was discussed with Me Nina Otto, a professional City and Town Planner. Part 2, the Mathematical model, was discussed with Me Cara Gerber, a professional Transportation and Strategic Planning Engineer. Some of the other typical questions asked and the answers gathered during these semi-structured interviews are provided in this Appendix.

Semi-Structured Interview with Me Nina Otto, City and Town Planner:

1. *According to your experience, what type of area functions the best as a closed area? Do the factors included in the location checklist cover the primary characteristics associated with a successful pedestrian zone?*

The answer to this question was that areas with mixed land use are considered ideal for pedestrian zones. The comment was made that the factors included in the location checklist address all of the important location parameters.

2. *Currently the model recommends that all of the location characteristics be met for the proposed pedestrian zone to be successful. Do you agree?*

The answer was that in the case where all of the checklist characteristics are met, the success is very likely; the authority using the model should however use their own discretion and motivations in the case where some checks are not met depending on the reasoning for this particular authority to install a pedestrian zone.

3. *Do you know of any other successful pedestrian areas that were implemented in an area where cars initially had priority?*

The example of the pedestrian zone near the University of Oxford was mentioned. One of the factors that contribute to the success of this pedestrian zone is that the authorities responsible for this pedestrian zone realised that parking cannot be completely removed. A park-and-ride system (parking elsewhere with a shuttle services) was therefore implemented.

4. *Do you think there is a better method to determine the success of a proposed area for pedestrianization? How is the location for a pedestrian zone currently determined?*

The answer to this question was that Transport Oriented Development (TOD) principles are currently considered when planning pedestrian zones form an urban planning point of view. Zoning schemes and land use policies are also taken into consideration. Currently there is no specific standard form to determine the location of a pedestrian zone.

Semi-Structured Interview with Me Cara Gerber, Transportation and Strategic Planning Engineer:

1. *According to previous studies, constant accelerating and decelerating movements cause the most traffic pollution. Currently the mathematical model calculates the air quality benefits by using a unit of vehicles removed daily. Do you think it is necessary to model parking movements additionally?*

The answer was that in the case where a very detailed answer is required it can be beneficial to include parking movements separately, but the model as it is currently, most likely include this factor already. By removing vehicles, the associated parking movements are also removed spontaneously. It will not make a significant change to add parking movements to the current model, since the model provides outputs as a positive or negative. In order to refine this aspect of the model specific streets can be used as input.

2. *Do the development of projects in the strategic planning industry take economic and social benefits into account*?

The answer indicated that these factors are certainly of high importance. In South Africa the economic feasibility of projects however drives the success of the projects. Social benefits however do have an economic value and should therefore be included in the decision making and planning process. With this question the recommendation was made to create a model where all of the factors currently addressed are provided in terms of an economic value and benefit. It was further concluded that a specific weight cannot be attributed to air quality, economic, social or traffic factors. The specific case will determine which factor is the most important and which benefits are aimed for.

3. *How does a change in the transport network impact the flow of traffic? Have you experienced the concept of "traffic evaporation" with a change in the transport network? What factors typically indicate the efficiency of a network? Delays and queue lengths are used in the model validation.*

Over a long enough period traffic will sort itself out and the network will return to a state of equilibrium. Therefore, with regards to the model validation, it should be considered that the previous study with which the model is compared does not stretch over a long enough period. It can be anticipated that if the time period is increased the model validation outputs will differ and indicate more positive changes. Queue lengths and delays are a good measure to determine the operations of intersections; it can however change drastically depending on the time of day.

4. *Is the mathematical model practical and is there a need for a model of this nature in the industry?*

The answer obtained for this question was that the industry will definitely benefit from a tool like this to aid in decision making. It will enable authorities to compare different project possibilities on the same grounds. Since it is an easy, quick and cheap tool to use, companies will also be able to save on costs prior to major investigations.

APPENDIX E: ETHICAL CONSENT FORMS