A Greenway Network for a more Sustainable Auckland

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Abstract

Since the early 1970s, there has been a growing understanding that the form and function typical to many urban areas is unsustainable. Significant problems are evident in many urban areas today, such as air, water, and noise pollution, lack of green/open spaces, and inefficient transport systems. Given urban areas are home to around half the world's population, it is vital that efforts are made to improve their sustainability for the well-being of present and future generations. This paper shows that greenways, especially greenway networks, are an important planning tool to improve urban sustainability. Essentially, greenways are linear green open spaces established along natural or man-made corridors. Their potential to enhance urban sustainability lies in the wide range of environmental, economic and social benefits greenways can provide. To employ this tool, a GIS-based methodology for planning greenway networks is proposed. The generation of these networks is based on a nodal and connectivity analysis and is supported through the GIS environment. Using this methodology, a master plan of a greenway network is developed for the Auckland Isthmus (New Zealand).

1. Introduction

Urban areas are great magnets to most humans. Indeed, around 2.8 billion people worldwide live in urban areas. They are an important resource in their own right, but also have become a threat to the natural environment. Urban areas are the nucleus of economic growth, the major sources of new technology and wealth. However, they also face significant problems: uneven urban development, creation of economic and social 'sink' areas, and environmental decay (urban areas are the major consumers of natural resources and the largest producers of pollution and waste). Furthermore, urban areas have a sphere of influence far beyond their own territory.

The massive increase in urbanisation and the impact of urban areas on the global environment mean that creating more sustainable urban areas is essential to sustainability at the national and international level. More than ever, the quality of life and the legacy to future generations depend on the degree to which urban areas are successfully developing in a sustainable way [10].

It has been argued that urban areas are and ever will be unbalanced in terms of environmental and socio-economic factors, since they 'consume' natural resources and 'produce' waste and pollution incessantly. The exceptional challenge is to try to compensate this situation. In this context, it can be said that much can be achieved through practical incremental steps in a direction that seeks to 'reduce urban unsustainability' as much as to 'achieve urban sustainability' [5]. Greenways, especially greenway networks, are one possible step to reduce these unbalance.

A greenway is a green linear open space established along a natural or man-made corridor. It is a landscape connector linking spaces with concentration of environmental, social, cultural and historic resources with each other and with people. It protects these resources and at the same time it provides green open space near people's homes and offers desirable aesthetic amenities to people as they recreate or commute along the greenway. A greenway is bordered with vegetation, separate from the traditional traffic roads, and ideally uninterrupted. Since it provides connections, it is a route for passage and movement of persons, animals, things and non-motorised vehicles. It is safe, pleasant, and easy to travel on. Its general direction is easy to recognise by its physical characteristics and the way in which it creates it own landscape. It is free to use and easy to access. A park along a river or a disused railway line converted for recreational use and as an alternative transport route are examples of greenways.

This paper presents the major outcomes of [14]. Section 2 of this paper establishes the relationship between urban sustainability and greenways. Moreover, the potential of greenways for a greater urban sustainability is demonstrated. As a result, it is concluded that greenways are an important planning tool in urban areas. In order to employ this tool, a GIS-based methodology for planning greenway networks is developed (section 3). This methodology is based on the interpretation of the landscape in [7], on the work in [9], and on graph theory. In section 4, the proposed methodology is applied to develop a greenway network towards a greater urban sustainability for the Auckland Isthmus. As a result, a master plan of a greenway network for the Auckland Isthmus is proposed. This paper closes with the conclusion (section 5) that greenways are an important planning tool in urban areas.

2. Greenways and Urban Sustainability

The explosive growth of urban areas has brought about fundamental changes, not only to the physical landscape, but also to people's perceptions of land and environment. The high concentration of population induces several problems, not only environmental (however important these are), but also economic and social. In other words, it induces problems and has an impact on the three parts of urban sustainability.

Greenways, because of their key characteristics such as spatial configuration and multi-functionality, bring to an urban area a wide range of benefits. Based on an exhaustive literature review, these benefits have been carefully analysed and identified in [14]. These benefits are grouped by the three parts of (urban) sustainability: environmental, economic and social (Table 1).

Environmental benefits	Economical benefits	Social benefits
Greenways: Help to restore and protect the natural environments Enhance environmental quality Contain different kinds of vegetation Support local plant and animal communities Provide wildlife corridors Support biodiversity Protect areas, in which waterways exist, that must be kept unpolluted Help to reduce flood hazard and ameliorate the water fluxes across landscapes Reduce problems of soil erosion and down-stream sedimentation Help to reduce journeys to and pressures on the countryside Induce a more efficient utilisation of land Limit urban growth Can be makers and shapers of the urban form	Greenways: Help inward investment, business retention and corporate relocation Induce positive publicity for business Enhance the facilities for employees Stimulate higher productivity Provide direct employment opportunities Attract tourism Enable commercial opportunities Improve the overall appeal of a community to prospective new residents Are a low public investment and a low private expense Increase real-estate property values Help create tax revenue Help to reduce public costs Stimulate expenditures by residents Stimulate agency expenditures Are a cost-effective strategy for providing outdoor recreation Decrease the car related family budget Reduce the need for a second car Proportionate a win of money and time for parents	Greenways: Improve leisure time and sport facilities Can be a means of education Enable a better appreciation and awareness of nature and the environment Are an alternative transport route Democratise the public mobility Enhance well-being through contact with nature Are a visual relief, especially in urbanised areas Induce healthier lifestyles Provide access and linkage between natural and cultural sites Help to preserve monuments and historical buildings Enhance sense of community Can be an anchor for revitalizing neighbourhoods and building healthy communities Facilitate social equity and therefore, social cohesion Are an alternative to those who do not live near traditional parks Can serve as evacuation and emergency vehicle routes Have a positive influence on human behaviour Help to reduce crime

Table 1. Greenway benefits (adapted from [14]).

Some of the greenways benefits are reinforced when they are connected in a comprehensive greenway network, linking the main significant areas of natural, ecological, scenic, social, economic, recreational, historical and cultural values of an urban area (Fig. 1.). A greenway network is in itself a green open space and therefore it brings to an urban area all the benefits of the more traditional urban green spaces. But a greenway network through its connection and linkage induces a larger spectrum of benefits. This linkage between areas is what makes a greenway network different from more traditional urban parks.

Through these benefits, greenways are a sensitive and appropriate response towards greater urban sustainability. In other words, greenways are a crucial planning tool and can help make progress towards greater urban sustainability as well as more general benefits. This can be summarised into seven topics [14]:

1) Quality of life – its achievement for all urban citizens based on the basic environmental, social and economic elements. Examples for basic environmental elements are potable water, breathable air, spaces for movement, desirable habitat for living, recreation and working. Some basic social elements are physical and mental health, access to education and housing, and equity. The basic economic elements are for example reliable employment, incomes that sustain a fair quality of life, and economic opportunities and diversity.

2) Land use planning – this is related to the irreversible land use changes and the pace at which land, a finite resource, is being consumed by urban development and urban sprawl.

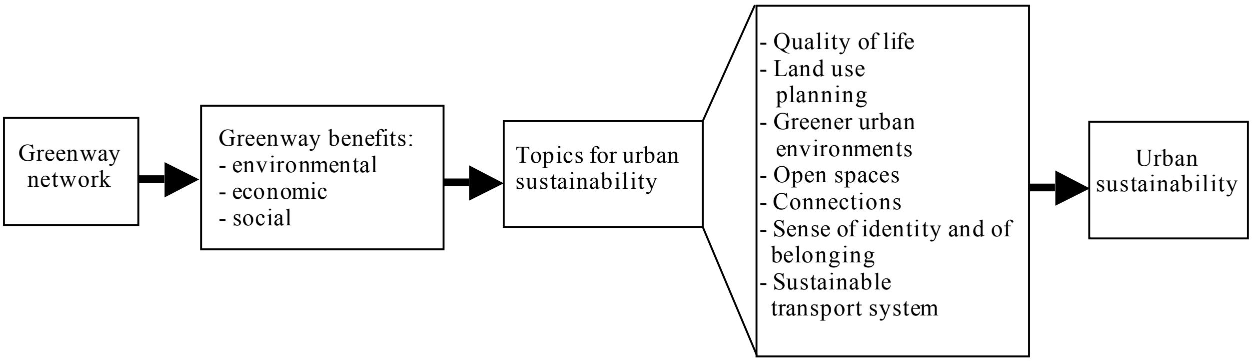

Fig. 1. Greenway network and urban sustainability [14].

3) Good connections – it is important to conserve connections from landscape to landscape, and space to space. In [1] it is argued that providing or maintaining connectivity in a landscape supports particular processes and functions that may not otherwise occur. If these processes are beneficial and valued by humans and are dependent on connectivity to some extend, then it can be argued that connectivity is an important characteristic of, or a prerequisite for, urban sustainability. Besides the ecological benefits, good connections have important social benefits, such as support of social cohesion and facilitate contact among people.

4) Sense of place, of identity and of belonging – urban areas through their design should support a dynamic urban cultural life and foster strong urban identities [10]. The sense of place and of identity can be enhanced in part by providing a distinctive character to an urban area, which in turn can be achieved through icons.

5) Development of a sustainable transport system – no urban area can offer good quality of life or achieve some level of urban sustainability without a sustainable transport system [15]. Integrated with land use planning, for all forms of transportation should also enhance the quality, liveability and character of communities and support revitalisation with minimum displacement within urban areas.

6) Greener urban areas and 7) Open spaces – the creation, protection and maintenance of green/open spaces are crucial elements of urban sustainability, as well as their accessibility by everybody ([4], [8], [12], [13]), especially the development of networks of (green) open spaces for the protection of natural resources ([5], [6]).

3. Methodology

The methodology here proposed is based on two premises. The first one is that greenways meld human and natural considerations and influence the urban landscape. The second premise is that every single thing is connected in time and space. This premise is based on the interpretation of the landscape in [7]. From these authors' perspective, the environment is a complex web of landscape elements that change and evolve overtime. For them the landscape is composed of patches and corridors that exist within a dominant background, the landscape matrix. The landscape matrix can be relatively uniform and homogeneous in character or highly heterogeneous and varied over space. Both patches and corridors contrast in appearance with the landscape matrix. The difference between them is that patches are non-linear areas, and corridors are linear arrangements of natural areas or elements that can be considered to be a place or an event. By viewing the landscape in terms of these basic structural elements, a network can be understood as a system of patches and corridors existing within and extracted from the landscape matrix.

Projecting these concepts for planning a greenway network (GN) in an urban area, the total urban area, or the total of the case study area, can be defined as the landscape matrix, the focal points of activity or nodes, as patches, and the greenways as corridors. The nodes can be any non-linear area that demands connectivity that is to be included in the GN. The third element of the system is the corridors or links, which are linear elements that facilitate the flow of energy, matter or species and are the main channels of movement.

As argued, a GN is composed of nodes and links. Therefore, it can be assessed based on network analysis theory and methods, in particular the popular graph theory. An important aspect of this theory is the concept of network connectivity, which is the degree to which all nodes in a network are linked.

The methodology for planning a GN proposed here consists of six major steps: 1) identification of goal and objectives, 2) land cover assessment, 3) nodal analysis, 4) connectivity analysis, 5) network generation, 6) evaluation of the outputs. This structure is partially based on that in [9].

Since the planning of a GN is about a change in the land use and requires a broad array of spatial information, a Geographic Information System (GIS) technology should be applied to support the steps 2 – 6 of the methodology and to assist in the physical design of the GN. Each of the six major steps of the methodology is separately discussed below.

Identification of goal and objectives (Step 1)

This step defines what is hoped the GN will be (goal) and what purposes it will serve (objectives). In planning a GN the definition of its goal and objectives are especially important because of its multifunctional character. When choices must be made between alternative nodes, alignments, network schemes or any other aspect of a GN, the goal and the objectives are the determining factors.

Land cover assessment (Step 2)

This step consists of the identification and generation of the nodes of the GN. Remember that the nodes are the areas of potential demand connectivity. In other words, an area that because of its characteristics, is important to have in a GN and needs to be linked to other areas within the GN. This step involves collecting, analysing and aggregating land use data in order to identify the demand areas and posterior creation of the nodes.

Nodal analysis (Step 3)

A very crucial task in planning a GN is the choice of the nodes that will be part of the network. The aim of the nodal analysis is to find the relative importance of each node, i.e. the need for connectivity for each node. The choice of the nodes is based on the goal and objectives of the GN. To achieve this, first the possible benefits that greenways can have according to that goal and objectives are defined. Then, a value reflecting the relevance of the benefit is attributed to each of these benefits, and the most relevant greenway benefits are chosen. Once this is done, the attribution of weights to each node can begin. The node weight (NW) represents the relative significance of the node in the study area towards the goal and objectives of the GN. It depends on two parameters: the node class weight (NCW) and a criterion value, which is normalised to the total criterion value of the study area. Hence, the NW is calculated with the following equation:

$$NW = \left(N_{criterion} / T_{criterion}\right) * NCW \qquad \text{(Eq. 1)}$$

where $N_{criterion}$ is the node criterion value and $T_{criterion}$ is the total criterion value of the study area. When a node belongs to more than one node class its NW is the sum of all partial NW, that is:

$$NW = \sum_{i=1}^{l} NW^{(i)} \qquad \text{(Eq. 2)}$$

Connectivity analysis (Step 4)

Connectivity is the level of the reciprocal action or influence of one node on every other node. According to [9] and [11], the most common model used to evaluate the connectivity is the gravity model, through the following equation:

$$C_{ab} = \left(NW_a * NW_b\right) / D_{ab}^2 \qquad \text{(Eq. 3)}$$

where C_{ab} is the connectivity between nodes *a* and *b*, NW_a is the node weight of node *a*, NW_b is the node weight of node *b* and D_{ab} is the distance between the node *a* and node *b*. The connectivity is determined for all viable links that will compose the GN.

Network generation (Step 5)

Several potential networks can be generated. Due to the complexity of networks no general technique, method or algorithm for the GN generation can be defined. However, three types of data necessary for generating a network can be identified: connectivity (Step 4), cost to user and cost to builder. When the gravity model is used these types of information are automatically implied. A guided GIS-based approach is here proposed to generate a GN, as discussed in the following section.

Evaluation of the outputs (Step 6)

This final step of the methodology consists of the choice of the most appropriated GN through the calculation of connectivity indices, such as the adjusted Gamma index, the Beta index and the distant-weighted adjusted Gamma, and thorough inspection and comparison of the alternative networks. These indices are based on the number of links of the network, the maximum viable number of links, the number of nodes, the total distance (length) of the alternative networks and the total distance (length) of the maximum viable GN.

4. Case Study – the Auckland Isthmus

In this section the proposed methodology is applied to the Auckland Isthmus (AI), New Zealand. The AI is a popular place to live because of its central location within the greater Auckland region, its proximity to major areas of work and recreation, the high standard of amenity found in many of its suburbs and its mild warm-temperate climate. The elements that contribute greatly to the amenity of the Auckland Isthmus are: its extensive reserves, its low density, its coastline margin along all its extent, its substantially built up characteristic, its volcanic cones, its heritage trees, and its historic buildings and places of archaeological significance. However, as with any modern urban area it faces problems.

In order to apply the above described methodology first the interpretation of landscape in [7] is projected to the AI. Consequently the entire area of the AI is regarded as the landscape matrix, in which the relevant areas that demand connectivity, i.e. nodes, as patches and the greenways as corridors are found.

Identification of goal and objectives of the Greenway Network for the AI

The goal of the greenway network (GN) planned here is to improve the urban sustainability of the AI. How? (1) By providing more sustainable alternative ways for movement through the AI based on the linkage of the areas that demand connectivity. Like this, Aucklanders have the choice and the opportunity to get around without a car, which can help to reduce the problem of road congestion. The proposed GN can also help both regional and local governments in their common objective: the promotion of walking and cycling in the daily routine. At the same time the GN (2) will help to protect land from development and to control urban sprawl, which is recognised as being crucial by Auckland City Council [2]. An open space to be successfully protected from development needs to have a positive function. It must be usable and useful to people. Therefore, the GN can be a powerfully strategy for land protection, since it has those characteristics. Further, the GN (3) will fulfil the intention of Auckland City Council that the existing open spaces and green spaces, schools, commercial and community facilities should be linked by a walkway system. All these kinds of areas are part of the here planned GN. They are the nodes of the GN. The GN (4) also will help to protect and preserve the existing open and green spaces of the AI and it makes them more accessible for Aucklanders. Through their improved accessibility and by protecting these spaces, the GN will reflect the recognition of their major significance for the Aucklanders' quality of life by the council. The GN will also contribute towards a key characteristic of quality of urban design defined by the New Zealand Urban Design Protocol (NZUDP). This key characteristic is the development of a green network that links private and public open spaces.

In conclusion, the four points discussed above represent the objectives of the here planned GN for the AI.

Land cover assessment

As discussed in section 3, the main purpose of the land cover assessment is to identify the areas that demand connectivity, which will constitute the potential nodes of the GN. The first task is the collection and analysis of the GIS data. The choice of the demand areas is based on three principles: (1) demand areas are locations where certain types of human activities take place, (2) the assessment of potential areas that demand connectivity, and (3) the potential role of these areas towards the goal of the GN. The identification of the demand areas is performed in the GIS environment, where each area is represented as a node. The node is defined by the central point of the corresponding demand area, which is originally a polygon. For the AI, 4889 nodes were created. These nodes then were aggregated in 12 groups, i.e. node classes, by similarity of function. The reason to group and create node classes is to capture the type of human activity that takes place in an area and not the exact activity itself, since the goal of this GN is to help improve the urban sustainability of the AI [14]. The 12 node classes are: 1) open spaces; 2) green spaces, examples are parks, cemeteries; 3) recreational – examples are ball fields, play grounds, sport places; 4) commercial – examples are shops, stores, take-away; 5) universities; 6) schools; 7) entertainment – examples are restaurants, cinemas, museums; 8) institutional – examples are libraries, community centres; 9) health – examples are hospitals, clinics; 10) business; 11) Auckland central area; 12) railway and bus stations.

Auckland central area has a significant economical, social and even environmental importance. It permits a huge amount of all types of human activity and is a central hub for movements to and from all points of the AI. Based on these facts, it was decided to define it as a major demand area, represented by an individual node class.

Nodal analysis

The purpose of the nodal analysis is to discover the relative importance of each node in relation to the goal and the objectives of the GN for the study area. Therefore, an attribute representing the need for connection, i.e. the node weight (NW), is created for each node. This attribute is based on the role that greenways are intended to play towards the goal of the GN for the AI. To achieve this, first the possible benefits that greenways can have towards urban sustainability are defined. A total of 48 benefits are collected, as listed in Table 1. These benefits are attributed a value, called the sustainability value (SV), that reflects the relevance of each greenway benefit to urban sustainability. The SV ranges between 1 and 6, being 6 the best SV. For example, the benefit *greenways help to enhance well-being through contact with nature* has a SV of 5.17 and the benefit *greenways help to preserve monuments and historical buildings* has a SV of 2.33. The SVs were developed based on a sound knowledge of the literature and informed judgement. A more detailed explanation can be found in [14]. This ranking gives an overview of the relevance of each greenway benefit towards urban sustainability. From the 48 initial greenway benefits, 32 are selected for this case study.

The next phase of Step 3 is the attribution of a weight to each of the 4889 nodes. Like this, the nodes are ranked with respect to their priority for linkage in the GN.

The NW is determined in two parts. Since the NW depends on the NCW, the first part is the calculation of the NCW. This calculation begins with the analysis of the relationship between each of the 12 node classes and each selected greenway benefit towards urban sustainability. In this case study, 384 combinations are considered (12 node classes x 32 greenway benefits). To each of these combinations a partial value (V_{ij}) between 1 (less relevant) and 6 (most relevant) is attributed representing the relevance of these combinations to urban sustainability. The total relevance of each node class i to urban sustainability (V_i) is then calculated through equation: $V_i = \sum_{j=1}^{32} V_{ij}$. Table 2 shows an extracted of those 384 combinations and their V_i values. Based on these values, the NCW is calculated through equation: $NCW_i = V_i / \left(max_{(1 \le k \le n)} V_k\right)$

With the knowledge of the NCW for the 12 node classes, the NW is calculated through equation (1) and equation (2). The criterion here used is the area size of the node. The representation of all nodes by their NW is shown in Fig. 2.

It is easy to predict that in an area like the AI, which has a large number of nodes (4889), it is not possible to connect all nodes. The challenge is to connect the most relevant nodes towards the goal of the GN with the best compromise between cost to user and cost to builder.

		Node Class											
	i	1	2	3	4	5	6	7	8	9	10	11	12
j	Greenway benefit	OS	GS	R	C	U	S	E	I	H	B	AC	RB
…	…	…	…	…	…	…	…	…	…	…	…	…	…
10	Induce healthier lifestyles	6	6	6	5	6	6	6	6	4	6	6	6
…	…	…	….	…	…	…	…	…	…	…	…	…	…
16	Increase real-estate property values	3	3	6	6	5	5	6	4	5	6	6	2
…	…	…	…	…	…	…	…	…	…	…	…	…	…
24	Attract tourism	4	6	6	4	2	2	5	3	2	1	6	3
…	…	…	…	…	…	…	…	…	…	…	…	…	…
	V_i	160	175	169	145	148	157	146	136	109	143	192	130

Table 2. Relevance of each node class towards urban sustainability (adapted from [14]).

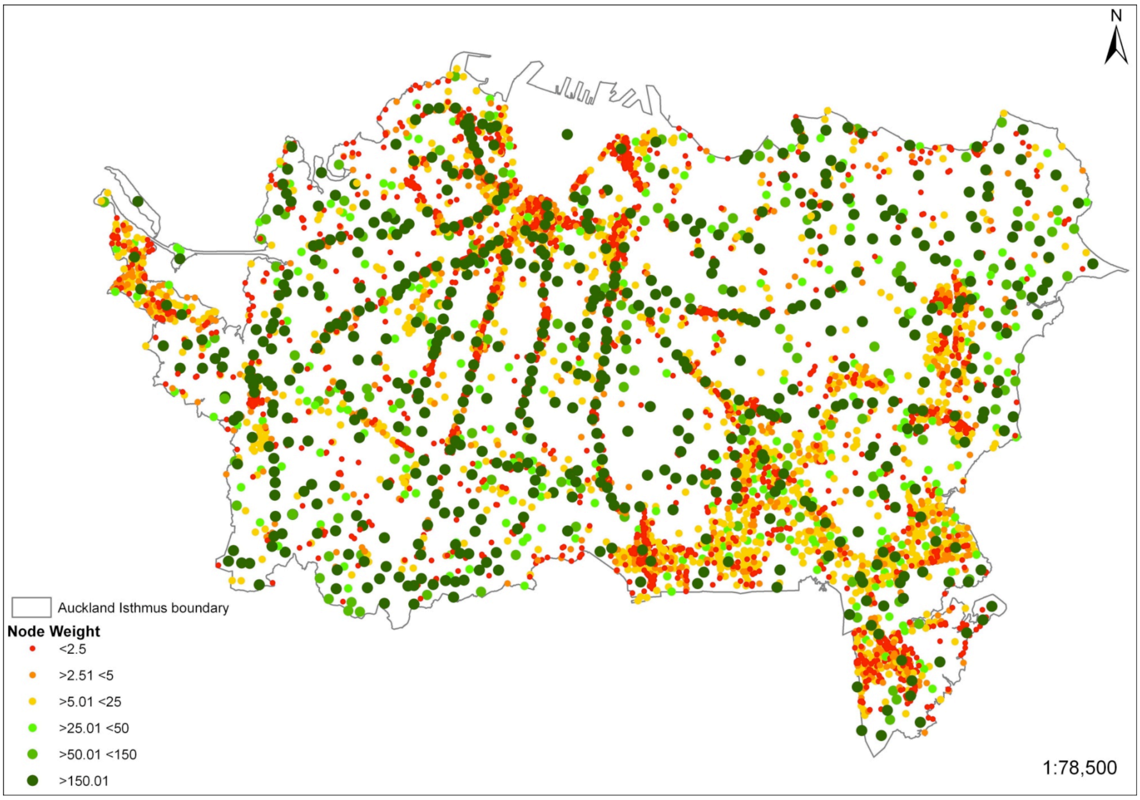

Fig. 2. Representation of all nodes by their node weight.

Connectivity analysis

For the determination of the connectivity using the gravity model, the NWs and the distances between the nodes must be known. The distances can be directly extracted from the GIS environment. The next task is the definition of the links, i.e. the greenways that should be regarded viable to generate the GN for the AI. It is considered that all direct links greater than 1.5 km length are non-viable. This decision is made based on the knowledge that a person is willing to walk circa 1 km and to cycle circa 3 km [3]. With this maximum distance of 1.5 km between two nodes, the destinations (i.e. the nodes) are roughly within a cycling and walking distance. Using this limitation, all viable links for the AI are generated in the GIS environment. A total of 587,602 links were generated for the AI. All these viable links compose the maximum viable GN for the AI.

Having generated all viable links, the determination of the connectivity for all those links is undertaken using the gravity model (equation 3).

Network generation

The generation of a network is based on the maximum viable GN. Obviously, the alternative GNs, which are generated in the following, are subsets of the maximum viable GN.

The large amount of nodes of the AI (4889) and the consequent enormous number of viable links (586,602) makes a manual network generation of an efficient network almost impossible. In the here proposed guided GIS-based approach, the user chooses certain strategic nodes which must be connected in a comprehensive network. Using the route function of the GIS environment the selected nodes are connected. Different results are produced depending on the selected nodes and the defined cost. Here, the intention is to use the connectivity (determined in Step 4) in order to generate the route between the selected nodes. In other words, the intention is to maximise the connectivity of the network. Like this, the route looks for the links that have greater connectivity in order to build the best network that links all selected nodes. This implies that beside the selected nodes other nodes that are connected by links with greater connectivity will also be part of the generated network.

Seven alternative GNs (A to G) were generated for the AI. For the generation of each alternative GN, different nodes were selected based mainly on their NW, and on which node class they belong. It follows the generation description for two of these seven alternative networks.

The GN F (Fig. 3.) is generated by linking nodes that have a NW greater than 431 plus 26 nodes of different NW, chosen manually. The intention of adding these 26 nodes is to have nodes at all the extremities of the AI's area in order to have a broader network.

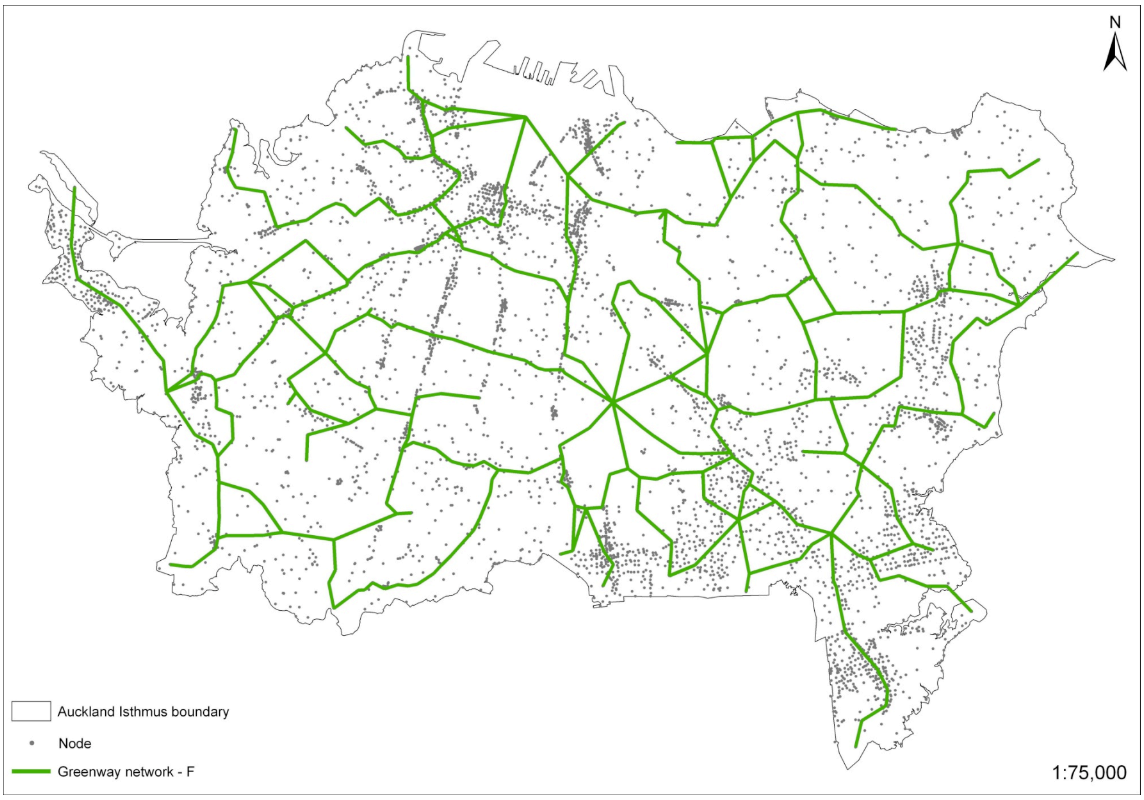

Fig. 3. The GN F for the AI.

The GN C (Fig. 4.) is generated by connecting all green spaces with a high NW plus nodes from all node classes that fall in a certain interval of NW values (between 120 and 430) plus the same 26 nodes used for the generation of the alternative network F. These are the selected nodes, which are connected by the route function to generate the network. The main intention of creating this GN was to guarantee that more green spaces are incorporated in the GN.

Evaluation of the outputs

The next and final step of the methodology is the evaluation of the seven alternative GNs. Here these alternatives are analysed and compared. This is done by manual inspection and using connectivity indices (section 3).

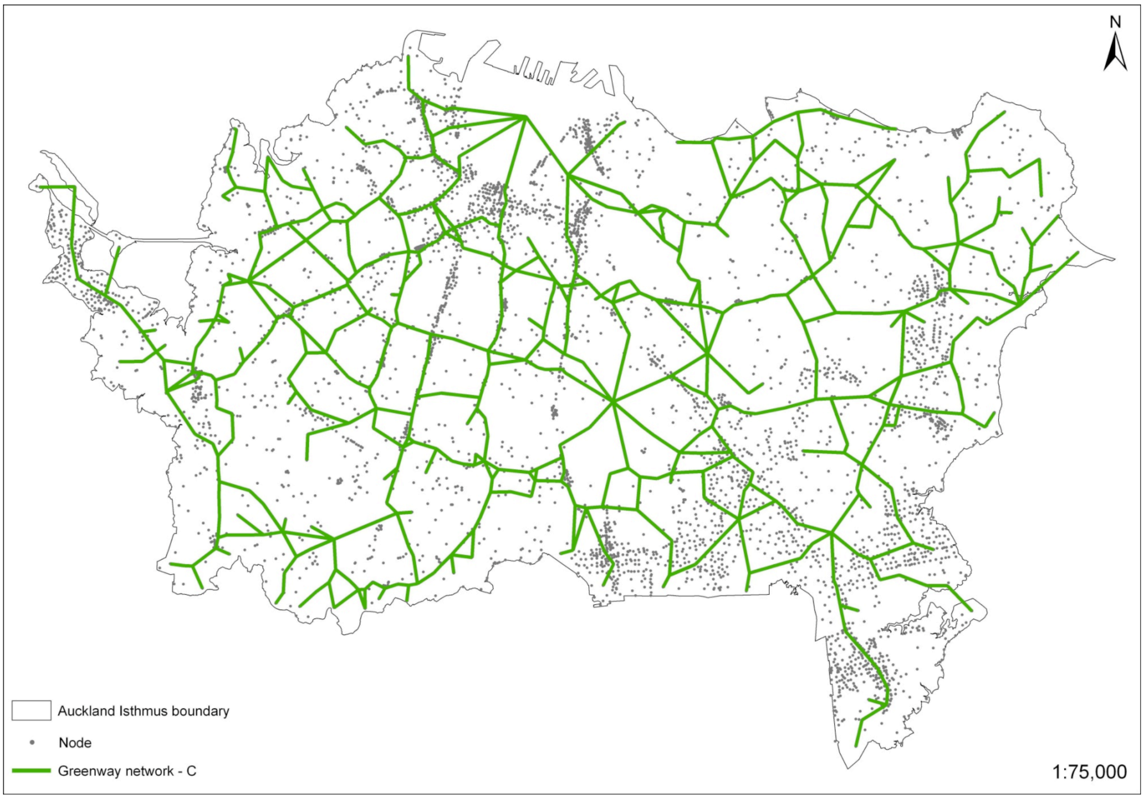

Fig. 4. The GN C for the AI.

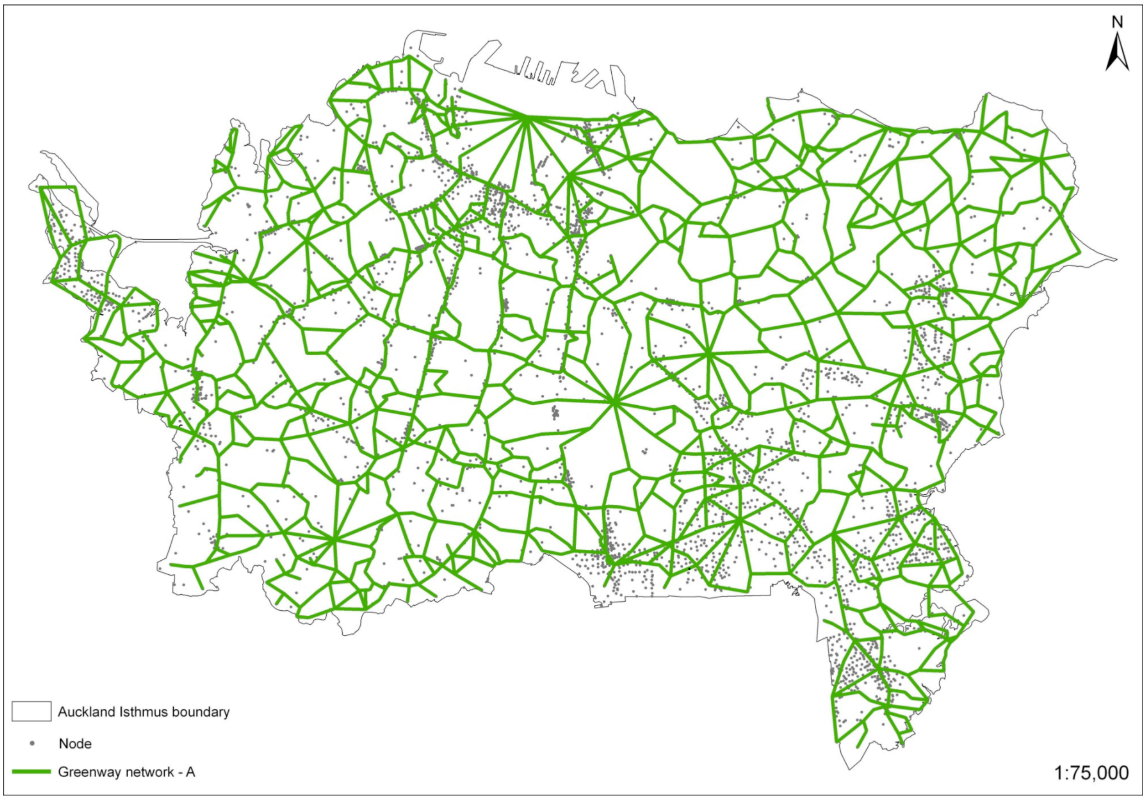

Fig. 5. The GN A for the AI.

It was observed that all seven alternative GNs have the same basic structure, i.e. main skeleton, independently of the nodes that were selected to generate the networks. These seven GNs represent a progressive decrease of network complexity from the GN A to G. That means that the cost to builder decreases and the cost to user increases from A to G. A very interesting and positive feature, which is common to all alternative GNs here generated, is that they do not consist of a hierarchical network typology with the node representing Auckland central area as the centre point of redistribution. They rather consist of multi-circuit[1] networks with cross town links.

Based on this evaluation it is proposed to start implementing the GN F and progressively upgrading until the GN C is reached. Ideally, once GN C is completely implemented, the implementation of the GN A (Fig. 5.) could begin. The here proposed GN should be considered as what it is: a master plan of a GN for the AI.

5. Conclusions

Greenways have the capability to protect and link natural, historical, cultural, ecological and economic resources into a type of system that has greater value and higher use than the sum of its parts. They respect the carrying capacity of the natural environment and they take into account the balance among the three parts of (urban) sustainability: environmental, economic and social. They help to make urban areas more environmental responsible, healthy, attractive, vibrant – in one word sustainable. They help to place particular emphasis on the question of how it is possible to move towards urban areas that are more enjoyable, more interesting, more humane, more legible and greener while using less energy, materials and water.

The main outcomes of this paper are: (a) greenways, especially GNs, are an important planning tool for achieving greater urban sustainability. Their potential lies in the wide range of benefits greenways bring to an urban area. (b) The development of a guided GIS-based methodology for planning a GN to apply this planning tool. The network generation is based on nodal and connectivity analysis and is supported through the GIS environment. This methodology is flexible and universal. It can be applied to any study area where the appropriate data is available or it can be assembled. (c) The creation of a master plan of a GN for the AI, which should be a guide for its effective implementation. Through these outcomes, this paper has demonstrated that greenways are a path towards urban sustainability.

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[1] A circuit is a closed loop.