STREET NETWORK CONNECTIVITY TOWARDS PEDESTRIAN WAYFINDING IN TELUK INTAN PERAK

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In the name of Allah, the Most Gracious and Most Merciful God,
Praise to Allah SWT for the abundant and grace, the Lord of the universe.
Peace and blessings be upon Prophet Muhammad SAW.

I dedicate this thesis to,
My beloved parents and parents-in-law who always trust and pray for the success of my career and continue to struggle in search of knowledge;
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Pulli Pangiran and Sitti Kappeli

My beloved wife who always understand and give support and encouragement along my journey in seeking knowledge;
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Nurliyana, Afzan, Syamimi, Irfan, Aiman and Adli

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Aisyah, Huzaifah, and Irdina

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ABSTRACT

The connectivity within a street network is a major consideration in the planning and design of a town. The overall effectiveness of a town design by considering the human connection with urban space encourages street environments towards a smart and efficient urban lifestyle. However, the spatial connection of human behaviour in a street network is influenced by the design and planning of street designs, patterns, structures, and character of the town. Malaysian towns have experienced various developments of street network that were planned, not only by colonialist ideologies, but also by various governments that came after Malaysian independence 1957, as well as developers who include architects, landscape architects and urban planners. The mixed designs of a street network cause negative effects towards pedestrian wayfinding, attributable to poor urban design, confusion in streetscape identity, and new developments that lead to the change of familiar environments to become unfamiliar. Therefore, this research aims to develop a spatial evaluation of street network connectivity for effective wayfinding behaviour in a small town in Malaysia. The town of Teluk Intan, Perak was selected as the study site based on the street network structures, patterns, designs, and characters of a Malaysian small town. In developing the evaluation, a survey questionnaire was distributed to pedestrians (n = 200), and then analyzed using SPSS to determine the index of fifteen street features that influence pedestrian wayfinding in this predefined context. With the aid of ArcGIS, the index was applied to produce a spatial map. Following this, axial-line data, convex-space data, as well as solid and void data were elicited from land-use data and Google images. In identifying the impacts of spatial connection, the data were analyzed utilizing the space syntax analysis from Depthmap. Next, the spatial map of street features and the spatial connection map were overlapped and analyzed to determine the spatial connection for wayfinding. The results were validated by triangulation from behaviour mapping and interviews (n=30). It was thus found that the combination of familiar street features strongly improved pedestrians' ability to identify their locations, positions, and routes to the destination better than from a feature. Furthermore, spaces with visualization, movement, and interaction assist pedestrians to identify street features, and lead to an effective wayfinding process. These findings provide more fine-grained insights on street network connectivity of small towns in Malaysia, especially those which help to improve wayfinding. As such, the findings suggest that for a small town in Malaysia to be systematic and organized, it is important to conduct a spatial evaluation of street connectivity prior to and during the planning stage.

ABSTRAK

Perhubungan rangkaian jalan merupakan pertimbangan utama dalam merancang dan merekabentuk sebuah bandar. Keberkesanan rekabentuk bandar dengan mengambilkira hubungan manusia dan ruang bandar menggalakkan persekitaran jalan ke arah gaya hidup bandar pintar. Walau bagaimanapun, perhubungan ruang tingkahlaku manusia dalam rangkaian jalan dipengaruhi oleh rekabentuk dan perancangan corak, struktur, rekabentuk dan karakter jalan di bandar. Bandar-bandar di Malaysia telah mengalami pelbagai perkembangan pembangunan rangkaian jalan oleh ideologi penjajah, kerajaan yang datang selepas kemerdekaan, dan pemaju moden termasuk arkitek, arkitek landskap dan perancang bandar. Gabungan rekabentuk dan pertimbangan perancangan rangkaian jalan mempunyai kesan negatif ke atas cari haluan pejalan kaki kerana rekabentuk bandar yang kurang sesuai, kekeliruan terhadap identiti persekitaran jalan dan pembangunan baru yang membawa kepada perubahan daripada persekitaran dikenali kepada tidak dikenali. Oleh itu, kajian ini bertujuan untuk membangunkan penilaian ruang perhubungan rangkaian jalan bagi tingkahlaku cari haluan yang baik dalam bandar kecil di Malaysia. Teluk Intan, Perak telah dipilih sebagai tapak kajian berdasarkan struktur, corak, rekabentuk dan karakter rangkaian jalan bandar kecil di Malaysia. Soal selidik yang telah diisi oleh pejalan kaki (n=200) telah dianalisis menggunakan SPSS bagi menentukan indeks bagi 15 ciri jalan yang mempengaruhi cari haluan pejalan kaki sebagai langkah pertama dalam membangunkan penilaian. Indeks berkenaan digunakan untuk menghasilkan peta ruang dengan bantuan ArcGIS. Kedua, data axial-line, data convex-space, serta data padu dan kosong telah diperolehi daripada data guna tanah dan imej Google. Data berkenaan kemudiannya dianalisis menggunakan analisis ruang syntax daripada Depthmap bagi mengenalpasti kesan perhubungan ruang. Ketiga, peta ruang ciri jalan dan peta perhubungan ruang digabungkan dan dianalisis untuk menentukan perhubungan ruang bagi cari haluan. Keputusan yang diperoleh disahkan dengan melakukan triangulasi keputusan terhadap pemetaan tingkahlaku dan temu bual (n=30). Dapatan kajian mendapati gabungan lebih daripada satu ciri jalan yang dikenali mampu meningkatkan kebolehan pejalan kaki dalam mengenalpasti lokasi, kedudukan dan laluan destinasi berbanding satu ciri jalan sahaja. Tambahan pula, ruang dengan visualisasi, pergerakan dan interaksi meningkatkan kualiti ruang dengan membantu pejalan kaki untuk mengenalpasti ciri jalan yang seterusnya membawa kepada proses cari haluan yang baik. Hasil dapatan yang diperoleh adalah signifikan bagi menawarkan pemahaman yang lebih baik terhadap perhuungan rangkaian jalan di bandar kecil di Malaysia terutamanya dalam meningkatkan cari haluan. Oleh itu, dapatan kajian menunjukkan penilaian ruang rangkaian jalan sebelum dan semasa peringkat perancangan adalah penting dalam mewujudkan bandar kecil yang sistematik dan teratur di Malaysia.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Performing good wayfinding when walking along a route to a destination allows a pedestrian to experience a pleasant journey, travel in less distance, save energy, and reach the destination the right time. Wayfinding is the ability and process of finding the route from an origin point to a destination point in a street network (Chen *et al.*, 2009; Courbois *et al.*, 2013; Hund and Padgitt, 2010; Hund *et al.*, 2012; Ishikawa *et al.*, 2008; Lin *et al.*, 2012; Sharlin *et al.*, 2009; Xia *et al.*, 2008). However, performing wayfinding is not always good. Pedestrians are exposed to an environment that encourages them to make mistakes or lose their way. Pedestrian familiarity with the street environment influences their perceptions of street features such as landmarks (Phillips *et al.*, 2013). The information gained from perceiving street features reflects their familiarity. The pedestrian is familiar when the information is in their memory, while the pedestrian feels unfamiliar when their knowledge on the information is weak (Chebat *et al.*, 2005; Gärling *et al.*, 1983; Sommer and Aitkens, 1982). Therefore, the information they gain and how they gain the information influence pedestrian familiarity in wayfinding.

The structure of street network can affect how a pedestrian gains information during travel. Street network is a space created from the intersections of streets in a small town (Tomko *et al.*, 2008; Wan Mohamad and Said, 2014). Hence, street network is used by pedestrians to move from one particular point to another. It works as a system in a town to achieve the functions of the town. The system consists of different types of streets according to their hierarchies, designs of street network, and

street patterns (Marshall *et al.*, 2014). The composition of a street network structure provides a variety in how a pedestrian perceives street features and gains their information. The connection of one street with the others influence pedestrian to be familiar or unfamiliar with the street environment (Hölscher *et al.*, 2009). Thus, the structure of the street network that provides better street connectivity influences pedestrian wayfinding process in a small town.

Connectivity of street network is generated according to the structure of the street network. The one that provides a space for pedestrians to visualize, interact or move influence the connectivity. Connectivity of street network refers to the number of links between nodes of street network that allow pedestrians to visualize, interact, and move from one point to another (Jiang *et al.*, 2000; Wan Mohamad and Said, 2014). Hence, connectivity is the connection through pedestrian visualization, interaction, and movement (Van Der Hoeven and Van Nes, 2014). Street network that allows pedestrians to perceive street features encourages them to gain better information. Along with the interaction space, it provides pedestrians the opportunity to ask others about the route to the destination, while the street network that influences pedestrian to walk can shorten their travel distance. Hence, a pedestrian's ability to define routes depends on the street connectivity of a small town in performing a good wayfinding process. Therefore, this research is conducted to explore street network connectivity and wayfinding of pedestrians in a small town. The purpose of this research is to develop a spatial evaluation model of street network connectivity for pedestrian wayfinding in Malaysian small towns.

This introduction chapter consists of ten parts. The first part introduces the chapter itself. The second part explores the background of this research, while the third part presents the research problem and its gap. The aim of this research is stated in the fourth part, followed by three research objectives. Then, the research hypotheses and questions are explained in the sixth and seventh parts respectively, in relation to the research aims and objectives. In the eighth part, the significance and the importance of this research in street network connectivity and wayfinding studies are described. It is followed by the ninth part of this research, which elaborates the scope of the study in the context of a street network and Malaysian small towns. Lastly, the structure of this thesis is presented in the part on thesis organization.

1.2 Research Background

In Malaysia, a small town is the center where people deal with their daily needs, with the total number of population size ranging from 10,001 to 100,000. A small town is structured with street network that allows the locals to perform their activities, including moving from one point to other points. In Malaysia, the total number of small towns is reported at 125, which is more than metropolitans and major towns at 99 and 17 respectively (JPBD, 2006; Mansor, 2011). Therefore, there is a need to develop well-connected street network for the use of pedestrian activities, specifically in moving from one point to another effectively.

A small town is structured with the design of street network associated to the experience of pedestrians using the town. A review on street network design suggests that the one with a gridiron pattern influences pedestrian to experience the town by either walking or biking and in turn reduces fatality (Marshall and Garrick, 2011; Rifaat *et al.*, 2011), while the street network structured with streets and junctions significantly generates street connectivity. However, streets with heavy traffic create conflict between pedestrians and vehicles (Carmona, 2014), whereas dead-end roads that allow pedestrians to move in a direction results in the worst wayfinding performance (Hölscher *et al.*, 2006). Meanwhile, pedestrians are motivated to reorient, look ahead, or make decisions for their wayfinding when stopping at a junction (Spiers and Maguire, 2008), especially at main ones (Lin *et al.*, 2012). Compared to a virtual environment, pedestrians fail to define the route for shortcuts to the destination when at junctions (Courbois *et al.*, 2013). This indicated that the structure of the street network that includes street patterns, street types, and junctions is associated to street connectivity. However, the studies have failed to define the usefulness of gridiron patterns for street connectivity in a small town. Moreover, the understanding on streets and junctions declines the relationship between typology of street and junction with street network connectivity.

Pedestrians experience a small town according to the connectivity of the street network. A high connection between main roads is found in pedestrian memory that is useful to process information on turns and route choices (Hölscher *et al.*, 2011). Meanwhile, low street connectivity is useful in avoiding barriers that

prevent direct routes and provide a few route choices (Koohsari *et al.*, 2014). Street connectivity allows pedestrians to visualize, interact, and move within the town. A high number of viewpoints allow broader views in defining route and recognizing the orientation (Sulpizio *et al.*, 2013), while low viewpoints lead to the negative effects of intervisibility in a small town (Van Der Hoeven and Van Nes, 2014). The visibility improves when pedestrians at junctions have the least angle between streets and direction line (Hochmair, 2005). Meanwhile, streets are also connected when the pedestrians are able to interact among themselves in the street. Communication and body language can solve spatial conflicts (Kataoka, 2013). Two-way communication between information providers and information receivers assists pedestrians in an unfamiliar street environment (Hund *et al.*, 2012). Studies indicated that spaces in a street network that allows pedestrians to interact can improve street connectivity for wayfinding. Besides visualization and interaction, street network is connected when pedestrians can walk in the town. The patterns of land use in street network can increase the density of pedestrian movement (Sheikh Mohammad Zadeh and Rajabi, 2013). Pedestrians are influenced to move in a street network with a design that connects land activities (Maleki *et al.*, 2012). Past literatures suggested that pedestrian visualization, interaction, and movement are significantly associated to street connectivity in creating engagement of the pedestrian with the town. However, studies have failed to explain the implication of street connectivity to pedestrian wayfinding. Moreover, the comprehension on pedestrian visualization, interaction, and movement declines the functions of street connectivity to wayfinding performance in a street environment.

Wayfinding performance is influenced by the familiarity of the pedestrians with the street environment (Phillips *et al.*, 2013). Street environment involves the composition and quality of street features such as landmarks, green spaces, and buildings. The significance of the features reflects its quality to pedestrian wayfinding: playfield or *padang* expresses important dimensions of social significance (Harun *et al.*, 2013); the facades of historic buildings and foods served at stalls give meaning to the locals (Carmona, 2014); landmarks represent the attraction of the places (Ferretti *et al.*, 2013); and open spaces and playgrounds allow children and teenagers to engage in outdoor activities in town (Mansor *et al.*, 2012). However, the investigation on the quality of street features that influences pedestrian

wayfinding perception is still missing. In addition, the literatures did not address the topic of how the quality of street features influences pedestrian wayfinding in small towns.

Familiarity, whether one is familiar or unfamiliar with the street features, influences pedestrians' perception towards the street environment. As a result, the street features reflect wayfinding behavior in a street network. In a virtual environment of the street network, pedestrians perceive street features differently (Iachini *et al.*, 2005; Lin *et al.*, 2012), which may be similar to a real-world environment. In a street environment, landmarks are more familiar than special buildings to pedestrians, even when both street features are useful in helping them become familiar with the street environment (Phillips *et al.*, 2013). Familiarity with facitilies in buildings such as airport terminals, shopping malls, or metro stations influences wayfinding of the users differently according to its visibility (Chebat *et al.*, 2005; Tam, 2011; Van Der Hoeven and Van Nes, 2014). The route selection is different according to the individual, whereby each pedestrian decides the route based on the street features that are always perceived at well-known streets (Hölscher *et al.*, 2011). Studies indicated that the perception of pedestrian towards each street features is different, however the understanding towards wayfinding perception among pedestrians when perceiving street features in a familiar or unfamiliar environment is still obscured in the literature. Besides landmarks and special buildings, the literatures did not address the usefulness of street features to pedestrians in a familiar or unfamiliar environment.

Pedestrians who perform wayfinding in a small town could be male and female pedestrians from various age groups. However, the discussion on the differences between males and females in wayfinding is still a controversial subject, in which the argument on males and females travelling differently or similarly is still in debate. For instance, Chebat *et al.* (2005) and Paydar (2013) indicated that males and females feel similiarly in an unfamiliar environment when perceiving unrecognizable features, whereas Iachini *et al.* (2009) described that males are better than females in defining routes. Hence, the debate in literature between genders in wayfinding requires further investigation.

Street features are found to influence pedestrian wayfinding in small towns (Lin *et al.*, 2012). Pedestrians are attracted to the physical appearance of street features, either from their designs or their colors. The attraction of a street feature gives impact to pedestrian attention (Borst *et al.*, 2009; Helvacıoğlu and Olguntürk, 2011; Kato and Takeuchi, 2003), but the similarity in design, either from the architectural form or physical form of the street features in different locations, confuses pedestrians with regards to the identity of the streets (Carmona, 2014; Hölscher *et al.*, 2006; Phillips *et al.*, 2013; Woollett and Maguire, 2010). Moreover, changes in viewpoints when perceiving a street feature decline pedestrian memory to the street environment (Sulpizio *et al.*, 2013). Studies indicated that street features are associated to pedestrian familiarity in wayfinding, but the reason of the street features in influencing pedestrian to become familiar or unfamiliar with the street environment is still questionable.

The composition of street features in a street network generates familiarity with spatial quality, either familiar or unfamiliar. Living quality conditions for the user of an area is improved with the composition of street features such as shophouses, parks, and common meeting places (Maleki *et al.*, 2012). Wayfinding involves the ability to refer, recognize, judge, define, and decide (Bryden *et al.*, 2013; Hidayetoglu *et al.*, 2012; Hund *et al.*, 2012). Hence, pedestrians perform better when perceiving a set of street features in 0º, 90º, and 180º in a familiar environment, while 0º or 45º in an unfamiliar environment (Iachini *et al.*, 2009). The review described that the composition of the street features generates the spatial quality that influence pedestrian wayfinding. However, the literatures did not present the spatial quality that is required for the pedestrians to perform good wayfinding or to avoid bad wayfinding. Besides that, the index for the street features is still unavailable. The visibility index suggested by Lam *et al.* (2003) in evaluating facilities in an airport terminal for wayfinding seemed fitting, but it requires further exploration for application in the street network of a small town.

In wayfinding, pedestrians behave according to the street connectivity and street features found in a street network. In connecting with the street environment, pedestrians are influenced to visualize, interact, and move (Jiang *et al.*, 2000). Travelling alone is associated to the difficulty in finding directions or location of

destinations (Antonakos, 2004). Wayfinding requires pedestrians to gain information, interpret them, and react accordingly (Xia *et al.*, 2008). Hence, pedestrians tend to learn and observe new information in an unfamiliar environment, which may be useful for their next visit (Chebat *et al.*, 2005). Past studies indicated that street connectivity and the familiarity of street features is associated to pedestrian wayfinding behavior. However, no evidence has been found to describe the relation of street connectivity and familiarity of street features with pedestrian wayfinding behavior. Therefore, the gap of the knowledge in the studies of street connectivity and wayfinding is stated in Section 1.3.

1.3 Statement of Problem and Research Gap

The development of street network involves the consideration of the pedestrians' daily needs. The street network of small towns, which are the highest number of towns in Malaysia, needs to serve 10,001 to 100,000 people (JPBD, 2006; Mansor, 2011). Hence, the structure of a street network necessitates the provision of a conducive environment that can connect pedestrians from one point to another in the town. However, issues arose from the literature in terms of limited knowledge in the well-connected street network for wayfinding. Table 1.1 presents eight issues between street connectivity and wayfinding studies relating to the types of patterns, streets, and junctions of street network, the behaviors of pedestrians related to street connectivity, quality of street features, pedestrians' familiarity, gender differences, spatial quality of wayfinding, as well as pedestrian wayfinding behaviors. According to these issues, this research suggests that the specific and exact problem is that the knowledge requires a model that can be used to evaluate street network connectivity for pedestrian wayfinding in a small town.

Table 1.2 presents the models that introduced the study of street network connectivity and wayfinding in six disciplines from 2000 to 2014: (i) transportation and health; (ii) computing, environment, and urban systems; (iii) environmental psychology; (iv) tourism management; (v) earth observation and geoinformation; and (vi) environment and planning.

Table 1.1: Issues highlighted in street network connectivity and wayfinding studies

Authors (Year)	Issues on street connectivity and wayfinding
Carmona, 2014; Courbois *et al.*, 2013; Hölscher *et al.*, 2006; Lin *et al.*, 2012; Marshall and Garrick, 2011; Rifaat *et al.*, 2011; Spiers and Maguire, 2008	The missing knowledge on the types of street patterns, streets, and junctions that can generate street connectivity for good wayfinding.
Hochmair, 2005; Hölscher *et al.*, 2011; Hund *et al.*, 2012; Kataoka, 2013; Koohsari *et al.*, 2014; Maleki *et al.*, 2012; Sheikh Mohammad Zadeh and Rajabi, 2013; Sulpizio *et al.*, 2013; Van Der Hoeven and Van Nes, 2014	The explanations on effects of pedestrian visualization, interaction, and movement functioning to wayfinding.
Carmona, 2014; Ferretti *et al.*, 2013; Harun *et al.*, 2013; Mansor *et al.*, 2012; Phillips *et al.*, 2013	The limited investigation of quality of street features that can influence pedestrian wayfinding perception.
Chebat *et al.*, 2005; Hölscher *et al.*, 2011; Iachini *et al.*, 2005; Lin *et al.*, 2012; Phillips *et al.*, 2013; Tam, 2011; Van Der Hoeven and Van Nes, 2014	The restricted understanding on wayfinding perception of pedestrian when perceiving street features in familiar or unfamiliar environment.
Chebat *et al.*, 2005; Iachini *et al.*, 2009	The unfirm directions on relation between genders and wayfinding.
Borst *et al.*, 2009; Carmona, 2014; Helvacıoğlu and Olguntürk, 2011; Hölscher *et al.*, 2006; Kato and Takeuchi, 2003; Lin *et al.*, 2012; Phillips *et al.*, 2013; Sulpizio *et al.*, 2013; Woollett and Maguire, 2010	Insufficient exploration on the reasons of how the street features influence pedestrian familiarity.
Bryden *et al.*, 2013; Hidayetoglu *et al.*, 2012; Hund *et al.*, 2012; Iachini *et al.*, 2009; Lam *et al.*, 2003; Maleki *et al.*, 2012	Limited investigation on the required spatial quality for good or bad wayfinding or to avoid bad wayfinding.
Antonakos, 2004; Chebat *et al.*, 2005; Jiang *et al.*, 2000; Xia *et al.*, 2008	The missing investigation in describing the relation of street connectivity and familiarity of street features with pedestrian wayfinding behavior.

Table 1.2: The models introduced in street connectivity and wayfinding studies

Study Area	Authors (Year)	Model	Concerns
Street Network Connectivity	Van Der Hoeven and Van Nes (2014)	Agent-based Modeling	People move through virtual environments in strange angles.
	Marshall *et al.* (2014)	Hierarchical Statistical Model	Measures intersection density and the link-to-node ratio.
	Koohsari *et al.* (2014)	Linear Marginal Model	Examines the association between street connectivity and the availability of utilitarian destinations.
	Hochmair (2005)	Least-angle Strategy	Accessing connectivity according to least angle.
	Jiang *et al.* (2000)	Space Syntax Approach	Measures connectivity of a street network design.
Wayfinding	Kneidl *et al.* (2013)	Hybrid Multi-scale Model	Links information between small-scale and large-scale navigation layers.
	Lwin and Murayama (2011)	Eco-friendly Walk Score	Walkability of pedestrian according to greenery.
	Sharlin *et al.* (2009)	Landmark-route-Survey	Divides environmental understanding into landmark, route, and survey.
	Borst *et al.* (2009)	Route Choice Model	Describes the influence of environmental street characteristics on walking route choice.
	Xia *et al.* (2008)	Four Wayfinding Model	Relation of levels of familiarity with physical environment.

Accordingly, five models were introduced in Table 1.2 related to street network connectivity, namely agent-based modeling, hierarchical statistical model, linear marginal model, least-angle strategy, and the space syntax approach. Even though the models are able to measure street connectivity comprehensively, they fail to measure street connectivity for wayfinding. Meanwhile, the five models that were introduced in Table 1.2 are used to measure pedestrian wayfinding in a street network. They are: hybrid multi-scale model, eco-friendly walk score, landmark-route-survey, route choice model, and four wayfinding model. Similarly, the models

were successful in measuring pedestrian wayfinding, but failed to relate with street connectivity. Therefore, the motivation for this study is to fill the gap in the knowledge by conducting a research to develop a model that evaluates street connectivity for pedestrian wayfinding. In addition, the evaluation model will be able to access the structure of street network, pedestrian familiarity on street features, and spatial connection that influence good wayfinding behavior.

1.4 Research Aim

The aim of this research is to develop a spatial evaluation of street network connectivity for pedestrian wayfinding in Malaysian small towns.

1.5 Research Objectives

There are three objectives formulated in this research in order to achieve the aim. They are as follows:

i. To investigate the quality of street features that influence pedestrian wayfinding perception in the street network of a small town;
ii. To identify the impact of spatial connection of street network on wayfinding in a small town; and
iii. To verify the spatial connection for wayfinding with pedestrian wayfinding behavior in the street network of a small town.

1.6 Research Hypotheses

This research started with the following three hypotheses to support the research aim and objectives: