ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

COMPARISON OF SHORTEST PATH AND LEAST RISK PATH ACCORDING TO THE 2D AND 3D VISUALIZATIONS FOR MULTILAYERED INDOOR SPACES

M.Sc. THESIS

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EN KISA YOL VE EN AZ RİSKLİ YOL ALGORİTMALARININ 2B VE 3B GÖRSELLEŞTİRİLMİŞ ÇOK KATLI BİNALARDA KARŞILAŞTIRILMASI

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FOREWORD

As a master student in Istanbul Technical University, I was always dreaming about studing in details on positioning and navigation for indoor spaces. In first place, I would like to give thanks to Prof.Dr.Ergin Tarı for his support and patience all the time which gave me self confidence and courage in my study. I am also greateful to Prof.Philippe De Maeyer and PhD students Ann Vanclooster and Kristien Ooms for helping me to finish the application part of my thesis in Gent University. I would like to thank my friend Chao Cheung Choi for all his encourements and professional suggestions about Geographical Information Systems. The most precious people I would like to thank are my mom and dad, without your support and your love, none of this would matter.

December 2014

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ABBREVIATIONS

AGPS	**:** Assisted Global Positioning Systems
AoA	**:** Angle of Arrival
APs	**:** Access Points
BIM	**:** Building Information Modelling
CityGML	**:** City Geographic Markup Language
DGPS	**:** Differencial Global Positioning Systems
DR	**:** Dead Reckoning
DoD	**:** Department of Defense
DOT	**:** Department Of Transportation
EGNOS	**:** European Geostationary Navigation Overlay Systems
ESA	**:** European Space Agency
FAA	**:** Federal Aviation Administration
GNSS	**:** Global Navigation Satellite Systems
GIS	**:** Geographical Information Systems
GPS	**:** Global Positioning Systems
IFC	**:** Industry Foundation Classes
IMU	**:** Inertial Measurement Unit
INS	**:** Inertial Navigation Systems
MEMS	**:** Micro Electro Mechanical Systems
MSAS	**:** Multifunctional Satellite Augmentation Systems
QR Codes	**:** Quick Response Codes
RFID	**:** Radio Frequency IDentification
RSSI	**:** Received Signal Strenght Indicator
TDoA	**:** Time Difference of Arrival
ToA	**:** Time of Arrival
ToF	**:** Time of Flight
TTFF	**:** Time To First Fix
UWB	**:** Ultra Wide Band
WAAS	**:** Wide Area Augmentation Systems

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COMPARISON OF SHORTEST PATH AND LEAST RISK PATH ACCORDING TO THE 2D AND 3D VISUALIZATIONS FOR MULTILAYERED INDOOR SPACES

SUMMARY

Thanks to the development of technology, navigation devices come into many people’s life. In daily life, people use Global Positioning Systems (GPS) to find their ways in both familiar and unfamiliar outdoor spaces. For indoor spaces, this technology is not popular as outdoor spaces. Because, GPS technology is limited since the radio signals can not penetrate through walls of the buildings. So other positioning techniques are used to determined the positioning and navigation in indoors. In this master thesis, the positioning techniques for indoor spaces are defined and the combination of indoor positioning techniques are explained. Since one of the positioning technique is not enough for positioning in a indoor space that’s why combination of techniques gives us so much better solutions to this problem. After the positioning techniques and their combinations are explained, the optimal routes for an indoor space are determined and Dijkstra’s algorithm and least risk path algorithm are explained in details with their examples. The aim of this thesis is to compare these two algorithm according to the different 2D and 3D visualizations of the floors. The case study building is chosen as “Plateau-Rozier” building of Gent University. Ground floor and first floor are modelled as Geometric Network Model and according to this model these floors are digitized in Sketch Up programme to visualize it 2D and 3D. Than from each node to every node all the single source shortest paths and least risk paths are calculated in C# software, and six routes are selected as a task where the shortest routes and least risk routes differs apparently. Each route consist of a source node and a end node and they have six visualizations to compare. The visualizations are 2D black&white and 2D color, 3D black&white and 3d color with version one, and 3D black&white and 3D color version two. After test is prepared with these routes and visualizations, fifty unfamiliar users are asked by some questions like “Which route is the shortest?”, “Which visualization do you prefer for solving a routing problem?”, and so on. According to the test, it is proven that people prefer shortest paths than least risk paths and they make their decision based on 2D visualization not 3D.

EN KISA YOL VE EN AZ RİSKLİ YOL ALGORİTMALARININ 2B VE 3B GÖRSELLEŞTİRİLMİŞ ÇOK KATLI BİNALARDA KARŞILAŞTIRILMASI

ÖZET

Gelişen teknoloji sayesinde, navigasyon cihazları bir çok insanın hayatına girmiş bulunmaktadır. Günlük hayatta, çoğu insan önceden bildiği veya bilmediği yerlere giderken Küresel Konumlama Sistemlerini kullanmaktadırlar. Fakat bu sistem iç mekanlarda, dış mekanlarda olduğu kadar yaygın olarak kullanılmamaktadır. Çünkü, bu sistem radyo sinyalleri ile çalışmakta olup, radyo sinyalleri duvarların içinden geçip bina içinde kullanılamamaktadır. Bu nedenle, iç mekanlarda konum belirleme ve navigasyon başka teknikler ile bazen de küresel konumlama sistemlerinin yardımı ile sağlanmaktadır. Bu yüksek lisans tezinde, iç mekanlar için kullanılan navigasyon teknikleri beş ana sınıfa ayrılmıştır. Bunlardan ilki GPS, ikincisi INS yani seyrüsefer sistemidir, üçüncüsü ses dalgaları ile konum belirleme yöntemi, dördüncüsü elektromanyetik dalgalar ile konum belirleme yöntemi ve beşincisi ile optik methotlar yardımı ile konum belirleme yöntemidir. Bu tekniklerden tek bir tanesi genellikle sonuç vermediği için, tekniklerin birlikte kullanımı iç mekanlarda konum belirlemek için çok daha iyi sonuç vermektedir. GPS ile INS kombinasyonu genellikle en yaygın olarak kullanılan konumlama tekniğidir. Bu teknik, bir çok uygulamada kullanılmıştır. Seyrüsefer sisteminin kullandığı temel sensörler olan hız ölçerler ve jiroskopların kalitesi sistemin doğruluğunu etkilemektedir. Bundan bir kaç sene öncesine kadar, bu sensorler oldukça pahalı ayrıca kullanıcıların günlük hayatta üzerlerinde taşıyamayacağı kadar ağır ve büyüklerdi. Gelişen teknoloji ile birlikte, MEMS adı verilen düşük maliyetli, küçük ve hafif sensorler seyrüsefer sisteminin günlük hayattaki kullanımını arttırmıştır. Ve şuan kullanılan seyrüsefer sisteminde bu sensorler kullanılmaktadır. Seyrüsefer sisteminde başlangıç noktasının doğruluğu önemlidir ancak bu sensorler düşük maliyetleri sebebi ile istenen doğruluğa ulaşamamaktadır. Bu nedenle doğruluğu arttırılmış olan GPS ölçmelerinden yararlanılır. Seyrüsefer sistemi optik methodlar ile kombinasyonunda ise başlagıç noktasının konumu optik yöntemler ile belirlenmektedir. Kullanıcı mekana ait önceden hazırlanmış haritayı akıllı telefonuna indirir ve daha sonra QR kodunu akıllı telefonların kamerası ile taratır. Daha sonra sistem kullanıcının tarattığı kodu çözer ve kullanıcıya o anki konum bilgisini verir. Sistemin kullanımı oldukça kolaydır fakat önceden navigasyonu yapılacak olan binanın haritalarının ve QR kodlarının hazırlanmış olması gerekmektedir. Ses dalgarı ile elektromanyetik dalgaların birlikte kullanılması yönteminde ise kullanıcının üzerine ses dalgası yayan ve radyo dalgarı yayan ve toplayan bir cihaz bulunur. Önce cihazdan radyo dalgaları yayılır ve bu dalgalar ses dalgası emisyonunu tetikler ve böylece tavana yerleştirilmiş olan alıcılar mesefayi hesaplar, böylece konum belirlenmiş olur. Son olarak, seyrüsefer sistemi ile electromanyetik dalgaların kombinasyonu açıklanmıştır ve bu kombinasyon daha çok acil durum senaryolarında kullanılmaktadır. Konum belirleme teknikleri ve bunların birbirleriyle olan kombinasyonları açıklandıktan sonra, iç mekanlar için harita üretimi konusu ele alınmıştır. İç mekanları iki ayrı

yöntem ile modellemek mümkündür. İlk yöntemde, koridorlar, odalar, duvarlar, mobilyalar, asansörler, mervivenler vb. iç mekana ait objeler BIM veya CBS ile modellenir. Bu modelde geometrik veriler objelerin öznitelik bilgilerine eklenir. BIM modelinde, binaya ait geometrik ve semantik bilgi sayısallaştırılmış halde bulunur. BIM modelinin en önemli özelliği, iç mekanların 3 boyutlu modellenmesine olanak sağlamasıdır. CBS'te BIM modeline benzerlik gösterir fakat bu iki model farklı amaçlar için geliştirilmiş modeller olduğu için aralarında belirgin farklılıklar bulunmaktadır. BIM modeli ile CBS modeli arasındaki en temel fark bu iki modelleme sisteminin detaylandırma düzeylerinin farklı olmasıdır. BIM modeli, iç mekanları en ince ayrıntısına kadar modellerken, CBS modelinde bu kadar detaya yer verilmez ve genel olarak geometri ve yüzeylere yoğunlaşılır. Bir diğer fark ise, kullanılan koordinat sistemi farkıdır. BIM modelinde, yerel koordinat sistemi kullanılırken, CBS modelinde evrensel koordinat sistemi kullanılır. BIM modeli, öznitelik verileri de dahil olmak üzere çok zengin bir veri yapısına sahiptir, bu nedenle CBS için very kaynağı olarak değerlendirilebilir. Ancak, BIM modelinden CBS modeline dönüşüm yapıldığında, BIM modelindeki very zenginliğinin bir kısmı kaybolur. Iç mekanları modellerken kullanılan ikinci yöntem ise nokta çizgi modelidir. Bu yöntem dış mekanları modellerken kullanılan yöntemlerle benzerlik gösterir. Modellemede en küçük birim hücredir. Hücreler, odaları, koridorları, duvarları vs. ifade eder. Basit bir hücre, tek bir noktadan girişi olan kapalı bir alanı ifade eder. Kompleks hücreler, bir çok noktadan girişi olan kapalı alanları ifade eder. Açık hücreler ise, sınırlarından en az biri açık olan, açık bir alanı ifade eder. Bağlayıcılar ise, katları birbirine bağlayan asansörler ve mervivenlerdir. Hücrelerin bir araya gelmesiyle çizgeler oluşur. Çizgeler yönlü ve yönsüz olmak üzere ikiye ayrılır. Bina içerisinde sınırlamalar varsa yönlü çizgeler kullanılır, sınırlama yoksa yönsüz çizgeler kullanılır. İç mekanların modellenme yöntemlerinden sonra iç mekan navigasyonu için bazı ideal rotalar tanımlanmıştır. Bunlar en kısa yol algoritması, en basit yol algoritması ve en az riskli yol algoritmasıdır. En kısa yol algoritması ağırlıklı ve ağırlıksız çizgelere uygulanabilen bir algoritma olup, Dijkstra'nın algoritması sadece ağırlıklı çizgelere uygulanabilmektedir. Dijkstra'nın algoritması iç mekanlara uygulanabildiği gibi dış mekanlarda da sıkça kullanılan bir algoritmadır. Ağırlıklı ilişkilerin göz önüne alındığı çizgelerde, her bir kenarın sayısal bir değeri bulunmaktadır. Fakat bu değer sadece pozitif değerler alabilmektedir. Algoritma tek bir noktadan tanımlanmış diğer tüm noktalara olan en kısa yolu iterasyon yöntemi ile hesaplar. Başlangıçta başlangıç noktası hariç tüm noktalar sonsuz değerini alır ve birinci iterasyonda başlangıç noktasının bağlı olduğu bütün noktalar içerisinde en küçük değeri alan nokta o an ki yeni başlangıç noktası olarak seçilir. Daha sonra bu seçilen noktadan iterasyon devam eder ve yine en küçük değeri alan nokta seçilir. İterasyon, sistemdeki tüm noktalar ziyaret edilene kadar güncellenerek devam eder. Ve ilk seçilen noktadan, diğer tüm noktalara olan en kısa mesafeler tespit edilmiş olur. Bazen en kısa yol, karmaşık bir yol olabilir. Bu durumlar için en basit yol algoritması yararlı olabilir. Bu algoritmada yolun kısalığından çok, tarif kolaylığı, hatırlanabilirliği, veya tarif edilen yolun bulunma kolaylığı gibi faktörler önem taşır. En basit yol algoritması genellikle en kısa yoldan daha uzun olmaktadır. İç mekanlar için kullanılan bir başka algoritmada en az riskli yol algoritmasıdır. Bu algoritmanın temel amacı kaybolma riskinin en az olduğu rotanın belirlenmesidir. Bu algoritmanın iki koşulu vardır. Birincisi, kullanıcının navigasyonu yapılacak olan mekana yabancı olması. Ikinci koşul ise eğer yalnış bir yol seçerse hata yaptığı noktaya geri dönmesi ve o noktadan yeniden seçim yapmasıdır. Algoritma genel olarak bir yol ayrımındaki yalnış gidilebilecek yolların

ağırlıklarına bağlı olarak çalışır. Bu tez çalışmasında Dijkstra’nın en kısa yol algoritması ile en az riskli yol algoritması örneklerle birlikte detaylı bir şekilde açıklanmıştır. Tezin amacı, en kısa yol algoritması ile en az riskli yol algoritmasının iki boyutlu ve üç boyutlu görselleştirmelerde göz önünde bulundurularak karşılaştırılmasıdır. Çalışma alanı olarak Gent Üniversitesi mühendislik binası olan “Plateau-Rozier” seçilmiştir. Giriş katı ve birinci katı daha önceki çalışmalar ile CBS ortamında modellenmiş ve bu model Sketch Up adlı programda iki boyutlu ve üç boyutlu olarak sayısallaştırılmıştır. Asansör ve merdivenler sadece bağlantı görevi görmekte olup, değerleri sabit 3 metre seçilmiştir, kapasiteleri ve uzunlukları hesaba katılmamıştır. Daha sonra, her bir noktadan diğer bütün noktalara olan en kısa yol ve en az riskli yol hesaplanıp, en kısa yol algoritması ile en az riskli yol algoritmalarının birbirinden en çok farklılık gösterdiği altı rota belirlenmiştir. Bu belirlenen altı rotanın ArcGIS programmında çizimleri yapılmıştır. Her bir rotanın bir başlangıç noktası bir de bitiş noktası bulunmakta olup, altı tane farklı görseli bulunmaktadır. Bu görselleştirmeler, iki boyutlu siyah/beyaz ve iki boyutlu renkli, üç boyutlu siyah&beyaz ve üç boyutlu renkli versiyon-1, ve üç boyutlu siyah/beyaz ve üç boyutlu renkli versiyon-2. Bu altı farklı görselleştirmeden toplamda dokuz adet farklı eşleştirme yapılmıştır. Kullanıcıların genellikle soldaki görselleri seçmeye yatkın olması dolayısıyla bu dokuz kombinasyona sadece sağ sol yer değiştirilerek dokuz tane daha görsel eklenmiştir. Yani toplamda ok sekiz tane farklı kombinasyon elde edilmiştir. Çalışma, elli kişi tarafından yapılmıştır ve üç temel soru üzerine yoğunlaşılmıştır. Bunlar; “Hangi rota daha kısa?”, “Hangi rota en basit?” ve “Hangi rotada en az dönüş vardır?” şeklindedir. Ayrıca, “Rota belirleme problemini çözmek için hangi görselden yararlandınız?”, “Hangi görsel daha estetik?” gibi sorulara da yer verilmiştir. Çalışmanın sonuçlarına göre, genellikle en kısa yol en az riskli yola göre daha çok tercih edilmiştir ve karar aşamasında iki boyutlu görseller üç boyutlu görsellere göre daha anlaşılır olduğu tespit edilmiştir. Ulaşılan diğer bir sonuç ise, en az riskli yol algoritması en kısa yol algoritmasından daha uzun olmasına rağmen, karar noktalarındaki risk değerlerinin en kısa yol algoritmasına göre daha az olduğu tespit edilmiştir.

1. INTRODUCTION

In the last decades, navigation is a big development for our lifes. Nowadays, almost every smart phone has a GPS unit and the users are increasing day by day. For outdoor spaces, GPS can be used to find the optimal way to provide convenience to the users in their daily life. For airports, hospitals, shopping malls or for emergency cases such as fire etc. inside the buildings, positioning and navigation in indoor spaces are quite important as outdoor spaces. But in indoor spaces there are almost no coverage of satellites that means GPS is not a solution for indoor spaces. That brings new solutions and developments for indoor spaces. The positioning techniques and navigation in indoor spaces in Figure 1.1, are actually a new study case.

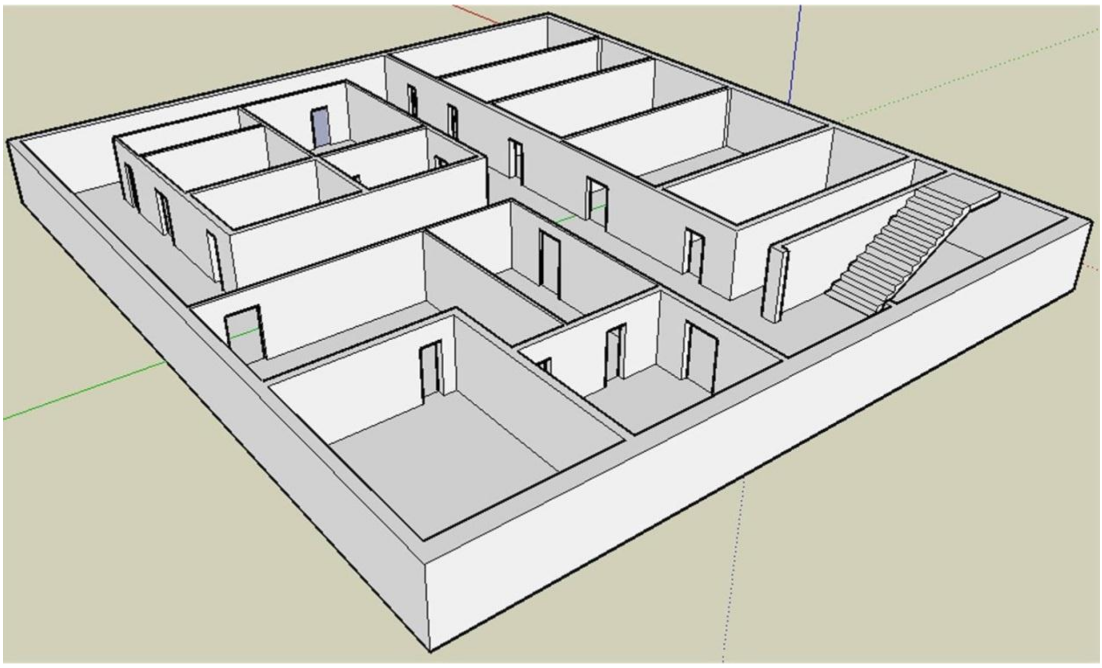

Figure 1.1 : Indoor space example (Yuan and Zizhang, 2008)

From that point of view, this thesis gives a summary of the main topics in indoor spaces. Chapter 2, explains indoor positioning techniques with their achieved accuracies; in chapter 3, the combinations of these techniques are explained because one of the positioning techniques explained in chapter 2 is never enough for required accuracy for indoor spaces; in chapter 4, representing indoor spaces on the maps and some cognitive algorithms for indoor models are explained; in final chapter, a survey is prepared to compare the shortest path and least risk path algorithm according to the 2D and 3D visualizations for multilayered indoor spaces, research is completed after 50 people filled the survey and the results are examined.

2. INDOOR POSITIONING TECHNIQUES

2.1 Global Positioning Systems

Nowadays many people use Global Navigation Satellite Systems (GNSS) to find their ways. The most popular GNSS is Global Positioning Systems (GPS) which is implemented by US Department of Defense (DoD) in 1973. GPS has three segments; space segment, control segment and user segment. The space segment consist of 27 satellites (24 operational and 3 active spare) but currently there are 32 satellites. The constellation of the satellites enable to the users at least four visible satellites from any unobstructed location on the earth. The satellites constantly transmit low power radio signals from space and these signals carries C/A code (with L1 frequency for civilians to standart positioning) and P-code (with L2 frequency for military to precise positioning). The control segment consist of a master control and monitoring station which is located in Colorade Springs and some other monitoring and uplink stations located in Kwajalein in North Pasific Ocean, Diego Garcia in Indian Ocean, Ascension Island in South Atlantic Ocean and Hawaii. The monitor stations constantly track and collect the signals from the satellites. They compute ephemeris and clock corrections for each satellite and transmit it to the control station. The uplink station are upload these data to the satellites. The user segment consist of GPS receivers and the users. GPS receivers collect and store the transmitted signals from the satellites. These signals include ephemeris and almanac data which are required to determine the user’s position by receivers. Four satellites are enough to determine a users position (latitude, longitude, altitude and time) and a direct line of sight between the receiver and these satellites is necessary. Although GPS designed for military purposes, both military and civilian can use the system. But for civilians there are some restrictions about accuracy. These restrictions are Anti Spoofing and Selective Availability. With anti spoofing restriction, civilians has no availibility of real P code. With selective availibility restriction, there were errors on satellite clocks and satellite coordinates but in May 2002, the US government removed the selective availability from the GPS signals so civilian can reach ten times more accurate positioning after that. Augmentation for the GPS can be in three ways; space based, ground based and inertial sensors.

2.1.1 Differencial global positioning systems

Modified form of GPS is called Differential Global Positioning Systems (DGPS). In this system there are two receivers, one is called the base receiver and the other one is called rover shown in Figure 2.2.

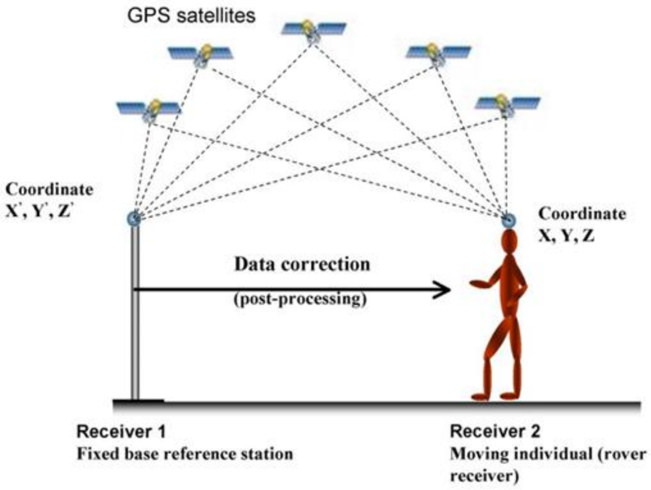

Figure 2.1 : DGPS (Terrier and Schutz, 2005)

The base receiver and rover are located close to each other like a few hundreds of kilometers, so it can assume that they are under the same atmospheric errors. The base receiver is located at a known position and computes all the pseudo range corrections for all observable satellites, these pseudo range corrections are called DGPS corrections. These corrections are broadcasted to the rover receiver. With DGPS the accuracy achieves less than half meter.

2.1.2 Assisted global positioning systems

GPS require a direct line of sight between the receiver and satellites. In outdoor spaces, these satellite based technology works properly but in indoor spaces there are insufficient or no direct line of sight at all. To enhance GPS performance in these conditions, a reference receiver (assistance) which has a direct line of sight sends the almanac and ephemeris data to the receiver via a wireless connection or a 3D cellular data. So the receiver does not have to wait for the satellites that the system allows the user to get quick initial position information. But the system requires installation of these asssistance devices which can be exclusive. This system is called Assisted Global Positioning System (AGPS) shown in Figure 2.2.

Figure 2.2 : A-GPS (Url-4)

The system is a combination of Global Positioning System (GPS) and wireless system. With this combination, time to first fix (TTFF) is enhace from minutes to seconds but the best precision is 15 meters which is still not enough for indoor navigation. So navigating in indoor spaces are provided by other techniques and sometimes these techniques are supported by satellite based technologies.

2.1.3 Augmented global positioning systems

Another augmentation for Global Navigation Systems (GPS) is also a ground based solution and covers wide area such as Wide Area Augmentation Systems (WAAS), European Geostationary Navigation Overlay (EGNOS) and Multifunctional Satellite Augmentation Systems (MSAS). Most populer ones are WAAS and EGNOS. WAAS is developed by United States Department of Transportation (DOT) and the Federal Aviation Administration (FAA) in 1994 and it is operational since 2003. It covers United States, Canada and Mexico. EGNOS is developed by European Space Agency (ESA), the European Comission and Eurocontrol in 2009 and its operational since 2005. It covers just europe but its being considered to extend it to southern europe and middle east. These systems are composed of three segments; ground segment, space segment and user segment. Ground segment is a network that includes ground based reference stations, master stations and uplink stations. The master stations collect and correct the reference station data caused by ionospheric disturbances, timing, and satellite orbit errors and generate the corrected signals and send them to the uplink stations. Space segment is composed of geostationary satellites which takes the corrected signals from uplink stations and transmits them to the receivers. The user segment is GPS receivers that can receive signals from the geostationary satellites and uses the corrected signals to improve the position accuracy.

2.2 Inertial Navigation Systems

Inertial Navigation Systems (INS) have been in use since the beginning of the twentieth century to navigate missiles through the air. Nowadays, they are used in many different fields such as aircraft, spacecraft, guided missiles and submarines. The term inertia is the tendency of the moving objects in a straight line as long as it is not acted upon by an external force. The Inertial Measurement Unit (IMU) consist of two kinds of sensors which are linear accelometers and gyroscopes. These are the devices which measures and reports the moving object’s velocity, orientation and gravitational forces. Linear accelometers are motion sensors which measure acceleration. They are the sensor that they receive one time velocity and two times the position. Gyroscopes are the rotation sensors which are used to determine the orientation of the acceleration all the time. Gyros measure the speed of rotation (rates) in units of degree per second or hour. INS has many different performance characteristics, but in generally they can divide to two categories; gimbaled platform systems and strapdown systems.

2.2.1 Gimbaled platform systems

Gimbaled platform systems are also known as stable platform systems. In this system the motion sensors mounted on a stable platform which is isolated from rotation sensors shown in Figure 2.3.

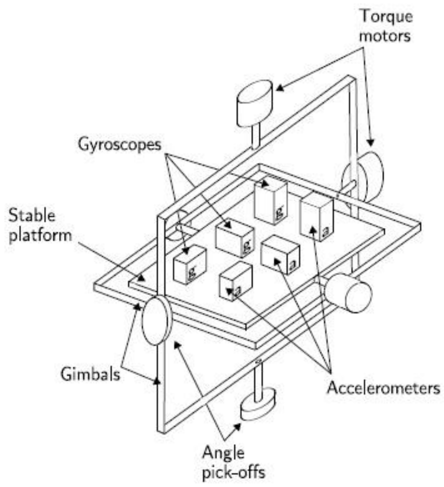

Figure 2.3 : Stable platform systems (Titterton and Weston,2004)

Gimbals (frames) allow interior of the platform to be isolated from rotations outside. Three gimbal bearings are sufficient in three axes which are named as roll, pitch, and yaw axes. Gyroscopes are inside the gimbals so they detect any platform rotations. Each gyro is connected to a torque motor which are fed back the signals to torque motor to null the rotation rates inside the gimbals. These torque motors keep the platform aligned with the global frame. This system uses very expensive tools but provides high accurate navigation data.

2.2.2 Strapdown systems

In this system the motion sensors are not isolated from rotation sensors except shock and vibration isolators. Instead of gimbals, the software calculates the accelometer outputs by computers in the body frame shown in Figure 2.4.

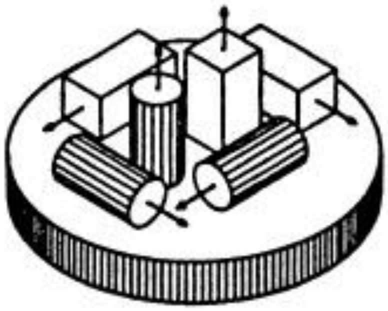

Figure 2.4 : Strapdown systems (Titterton and Weston,2004)

This system needs more calculations and removes the need of gimbels so its cheaper than gimble system. Gimbaled platform systems are the first INS and now they are still used in the applications which requires high accuracy like ship navigation. This system does not fit in the indoor navigation because its size and weight and for personal usage its very expensive. So the new technology enables the INS in indoor spaces by using strapdown based Micro Electro Mechnanical Systems (MEMS). These sensors are cost effective, small and lightweighted.

2.3 Sound Based Systems

Sound Based Navigation Systems use ultrasonic pulse to determine three dimensional position in indoor spaces. This system requires transmitters and receivers to send and receive ultrasonic pulses. This technique is called active bat system. Initilization of the system can be done by two ways. First, transmitter and receiver can be both set up on the navigation devices. Second, transmitter can be set up on the navigation device and receiver can be set up in the walls and ceiling of the building to be navigated. In this system, the time of flight (ToF) of the ultrasound signal between receiver and transmitter is measured. The system requires a synchronized clocks for all the receivers. Location of the transmitter is determined by trilateration technique which is a positioning method that uses the known positions of the reference points and the distance between the object and each reference point. The accuracy is usually less than 10 cm. To navigate in a building with the active bat system, the receivers has to be set up before and since the ultrasounds can not penetrate throught the walls, there has to be direct sight between receiver and transmitter.

2.4 Electromagnetic Wave Based Techniques

In Electromagnetic Wave Based Techniques, the positioning can be achieved by using infrared, radio waves or laser lights. Nowadays, infrared based positioning systems are developed and other techniques are founded. There are three kinds of measurements are done with light; the Received Signal Strenght Indicator (RSSI), the Angle of Arrival (AoA), and the Time of Arrival (ToA) or the Time Difference of Arrival (TDoA).

2.4.1 Infrared based techniques

The first indoor positioning systems that were developed used infrared sensors (Tseng et al., 2001). In this systems, several transmitters are mounted on different places in the building such as walls,corridors etc. and they transmit their ID all the time. A receiver uses these signals to determine its current location. The disadvantage of the system is the obstacles can block the infrared signals easily.

2.4.2 Radio wave based techniques

Radio waves such as WiFi, Ultra Wide Band (UWB), Bluetooth are able to penetrate through the walls and obstacles so a direct line of sight is not necessary in this method. This technology has two phase; offline phase and online phase. The firt step is called the offline phase and it comprises the fingerprint database of the building to be navigated. This fingerprint database is composed of points that are captured and saved in the user end database in the monitoring center. These points are measured according to the RSSI approach . The second phase is called online phase and in this phase Wifi signal measurements are done with the tags. The WiFi network is composed of Access Points (APs) which can be considered as the base stations. Their positions is already known and they generate the WiFi signals in indoor spaces. A tag is attached to the object which it's position will be determined. By matching the tag's current WiFi fingerprint in the database, the current position of the tag can be estimated. To estimate a tag's position, at least three different fingerprints needed from database. The accuracy depends on the number of Access APs and it achieves up to 2 meters. For the UWB signals, the measurement unit is ToA. In this system WiFi signals, UWB signals and Bluetooth signals can be used and this system works just in local area circumstances.

2.4.3 Radio frequency identification based techniques

For near field areas, Radio Frequency IDendification (RFID) method used to detect proximity. There are active and passive tags which means the systems is a low cost system. This system is progressed version of the infrared system, again the tags are mounted in walls, corridors or etc. and they always transmits signal. When the user pass close to a tag, the receiver gets the signal and determines his current location. The accuracy achieves centimeters in passive tags and meters in active tags.

2.5 Optical Methods

Navigation with Optical Methods are based on visual information provided by camera. This visual information can be stable or continuous. In this method, a system composed by optical markers has to be designed. These markers encoded by the marker's position information in the desired accuracy. There are two common makers which are 2D bar codes and quick response codes (QR codes). 2D Bar codes are scanned by the photo camera of the smart phone and decoded by it. QR codes are the extention of the 2D bar codes and they are use for determing the position of the marker. These encoded markers need to be well designed of the building to be navigated and the navigation device needs to be close enough to the encoded marker to get a viable position fix. The systems accuracy depends on the accuracy of the determined encoded marker's position.

3. COMBINATION OF THE POSITIONING TECHNIQUES

3.1 Combination of Inertial Navigation Systems and Global Positioning Systems

The integration of INS and GPS have been used for so many applications so far. INS has two main sensors which are gyroscopes and accelerometers. The accuracy of INS depend on the inertial sensor's quality. A few years ago, these inertial sensors was very pricy and their weight and size was improper for human motion capture. Recenly, MEMS made it possible to produce low cost, small and lightweight inertial sensors and with this improvement of the technology, INS became common for the pedestrian navigation. So nowadays the INS used for indoor navigation are based on the MEMS but these low cost inertial sensors do not provide adequate accuracy and performance. Because of the low accuracy of these sensors, INS needs to be integrated with GPS to increase the accuracy for indoor spaces. In INS, an accurate starting position is required. This starting position usually obtain from a GPS antenna. To stabilize the altitude measurement barometric sensors are used. To improve the performance of GPS, a modified form of GPS can be used.

3.2 Combination of Inertial Navigation Systems and Optical Methods

Recent developments in technology enables IMU mounted inside the smartphones. In INS, a known starting position is required because the current position is always determined from the previous known position, so the initial position for the start is necessary. This system is called Dead Reckoning (DR). For the initial position, user takes a photo of QR Code which provides the location informationd. This location information can be coordinates or URL. The system is very user friendly and easy. First the user needs to download the maps of the floors of the building to be navigated, scans the QR code with the photo camera of the smartphone. Than the system decodes a datamatrix in the QR code and initialize the current user location. When the initial position obtained from QR Code, INS start navigation.

Accelerometers calculate the distance travelled from the initial position and the gyroscopes determine the direction of the user.

3.3 Combination of Soundwave Based Systems and Electromagnetic Wave Based Sytems

There are two main difference between sound waves and electromagnetic waves. First difference is sound waves are longitudinal waves since electromagnetic waves are transverse waves. This means that sound waves need medium to travel while electromagnetic waves do not. Second difference is electromagnetic waves travel at the speed of light that is faster than speed of sound. Combination of these two system is similar to the active bat system. Bats have ultrasonic transmitter and radio transreceiver. Inside the building, there are radio transmitters mounted in the ceiling. First, a bat transmits radio signals, and triggers ultrasonic emission. So the receivers in the ceiling stop inertial calculation and compute the distance between the bat and the receiver. Three nodes are enough to compute 3D position of the bat. The accuracy achieves several meters. This combination is better than using each technique seperately because if it reduces the pre-configration of the location of the reference stations in the ceiling.

3.4 Combination of the Electromagnetic Wave Based Systems and Inertial Navigation Systems

This combination is generally used in emergency scenarios. In this combination, MEMS systems are choosen as the inertial navigation system because they are mobile and independent from the indoor space structure. In indoor environments, MEMS works in dead reckoning mode and their low cost devices reduces the accuracy of the inertial navigation system. Although, some inertial sensors can maintain accuracy of a few milimeters for one second, the positioning error caused by sensor drift will exceed a meter in ten seconds. In a dead reckoning approach, this positioning error accumulation is linear to the number of user's steps. (V. Renaudin, O. Yalak, P. Tome, B. Merminod, 2007) MEMS can use the WiFi techniques to get the initial position.

4. OPTIMAL ROUTING IN AN INDOOR MODEL

4.1 Modelling Indoor Maps

Maps for outdoor spaces and indoor spaces differs from each other because of their requirements. In indoor spaces the scale is larger than outdoor spaces that's why the accuracy must be higher for indoors. According to Brown, Nagel, Zlatavona, & Kolbe, 2012; Diehl et al., 2006; Hijazi, Zlatavona, , & Ehlers, 2011; Isıkdag, 2006; Isıkdag et al., 2008; Yuan & Zizhang, 2008; Zlatovana, 2008, the conceptual requirements for a building model for supporting and facilitating intelligent 3D indoor navigation appeared as:

1. Semantic information, i.e. a clear definition (and naming) of building storeys, elements, spaces, as their usage would support better orientation and guidance.
2. Properties of each building element (e.g. material of the walls, opening directions of the doors, doors used as exits) to support routing and better orientation/guidance during navigation.
3. Functional states of the building elements and moveable objects (e.g. door can be 'open' or 'closed', a furniture can be acting as an obstacle) and temporal changes in the building (such as areas that can be inaccessible for a time period) to reflect the temporal states for facilitating the real time navigation guidance.
4. Information on structural elements for the 3rd dimension (including vertical elements such as columns, walls, stairs) to support navigation to targets hidden in vertical dimension (such as pipes and cables) which are not present on a 2D map.
5. Spatial relationships between the elements (e.g. wall can be a container of opennings, a column can be connected to a wall, two floors can be connected with a stairs, etc.) to facilitate the deviation of the navigation network.
6. Building elements and spaces defined with 3D interoperable geometric

representations, such as defined in ISO 19107 (OGC, 2011) to facilitate the seamless exchange/sharing of geometric information between various applications and indoor and indoor/outdoor navigation.

Considering the requirements, there are two approaches to represent indoor spaces in a map. The first approach is Building Information Modelling (BIM) or Geographic Information Systems (GIS), second approach is Node Link Network.

4.1.1 Modelling with BIM and GIS

In the this approach, all the components of an indoor space such as corridors, rooms, walls, furnitures, elevators etc. are modelled by BIM or GIS. Then the geometric information is added to these digital format as an object attribute. These enables to the user to do topological analysis. BIM is a digital representation of detailed geometric and semantic information of a building. From another point of view, BIMs are object oriented building systems that provides time, cost, accessibility information additional to the X, Y, Z coordinates. Building components such as building geometry, spatial relationships, geographic information, quantities and properties can be modelled by BIM. The main importance of BIM is that it enables to work with 3D models of the representation of the indoor space. BIM's data format is Industry Foundation Classes (IFC) in Figure 4.1 which is an object oriented file format with a data model developed by buildingSMART (International Alliance for Interoperability, IAI). It is registered in the ISO 16739.

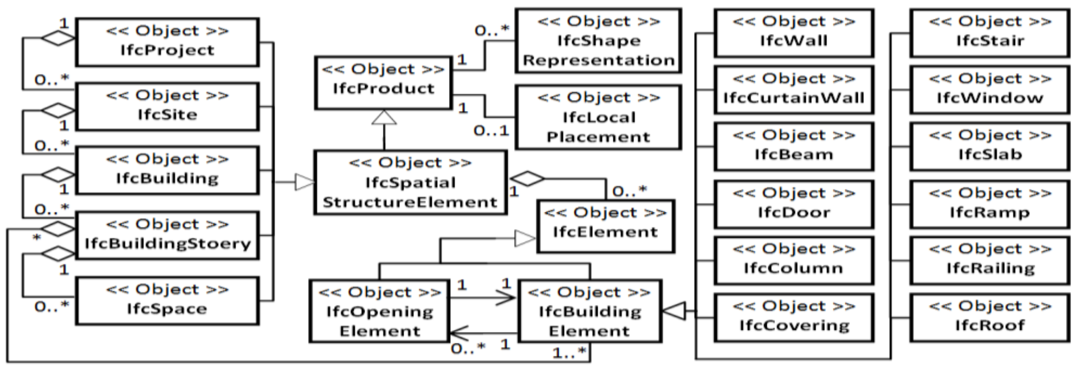

Figure 4.1 IFC Building Model (Mekawy, Östman and Hijazi, 2012)

Another similar way to model indoor spaces is Geographical Information Systems (GIS) which uses City Geographic Markup Language (CityGML) data model with XML format to represent indoor spaces. CityGML is also a digital representation of geometric and semantic information of a building. CityGML based on ISO 19100 standards and XML format refers to standards of W3C in Figure 4.2.

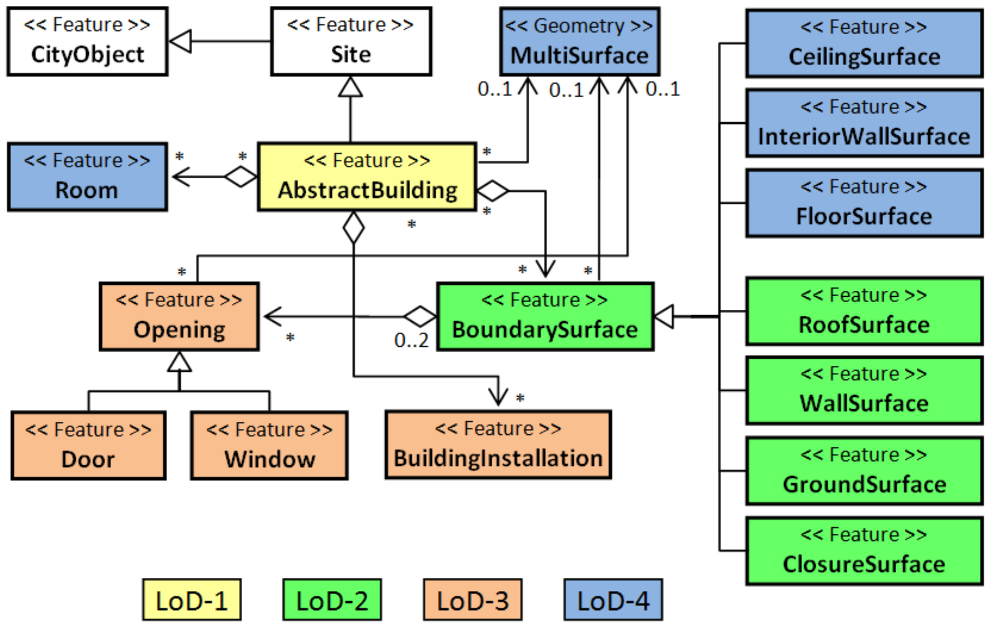

Figure 4.2 CityGML Building Model (Mekawy, Östman and Hijazi, 2012)

CityGML and BIM are developed by different purposes. The main difference is that they have different level of details for example BIM captures every details in an indoor space while CityGML just focus on the geometry and the surfaces. Another important difference is BIM uses local coordinate systems while CityGML uses universal coordinate systems. BIM models have rich data models with their attributes so they can be used as an input data in GIS. With the purpose of providing a successful 3D indoor navigation, it is necessary to transfer 3D geometric and semantic information from BIM into a 3D GIS environment (Isıkdag, 2006). After transformation BIM to CityGML, there can be some building components missing and most of the semantic information that BIM has will be lost because CityGML has reduced semantic information.

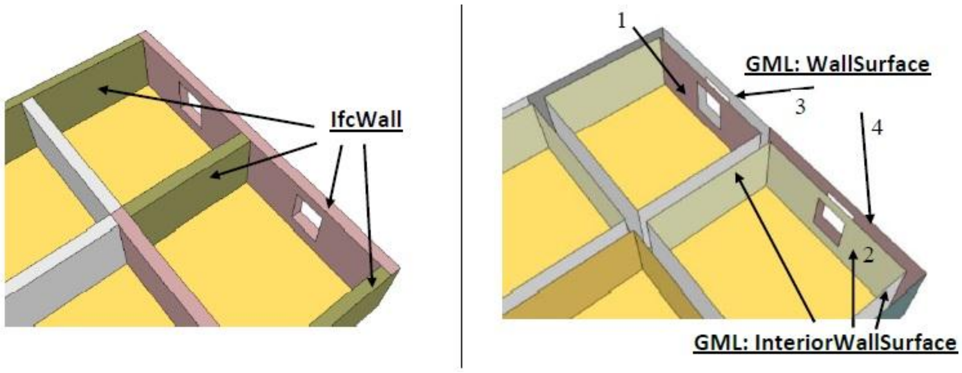

Figure 4.3 An example for difference between IFC and CityGML (Mekawy, Östman and Hijazi, 2012)

In Figure 4.3, walls are shown in both IFC standarts and GML standards. In IFC standards each wall represented separately but in GML standards all the walls represented as a wall surface which means they comes from the different level of details they use.

4.1.2 Node link model

The node link model is similar approach to modelling outdoor maps, it consist of the floor geometry so it allows the geometrical analysis. In node link model, the simplest unit of the model is called cells. Cells are rooms, corridors, walls and so on. There are four types of cells which are simple cell, complex cell, open cell, and connectors. A simple cell is a cell that is closed by walls and can be accessed by only one access points (Yuan & Schneider). A door can be an example for simple cell. A complex cell is a cell that is closed by walls and can be accessed by multiple access points (Yuan & Schneider). A room can be an example for complex cell that can have more than one access points. An open cell is a cell for which at least part of its boundry is not closed by explicit walls or other constraints. (Yuan & Schneider) Halls and lobbies can be an example for open cells. A connector is an object that connects different floors in a building. (Yuan & Schneider) Elevators and stairs can be an example to the connectors. Combinations of these cells represents graphs. Graphs can be directed or undirected. Directed graphs are also known as accessibility based graphs. These graphs are used when there are some restrictions. For example some rooms can be inaccessible for some users or some rooms can be inaccessible for some hours in a day etc. Undirected graphs are also known as connectivity based graphs. Graphs are navigating the routes to be followed.

4.2 Cognitive Algorithms For An Indoor Model

So far the indoor positioning techniques and their combinations are explained to determine the location information and tracking the objects in indoor spaces. These are the solutions for online routing problems in indoor enviroments. From now on, the state dependent routing and the optimal routes will be determined for an indoor space. The state can be the shortest route, the simplest routes, the least risk routes, the least time consuming routes and so on. Also users can determine the state of the route themselves. So optimal route can vary according to the user requirements.

4.2.1 Dijkstra's algorithm

Shortest path algorithm can be applied in both unweighted graphs and weighted graphs. Dijkstra's algorithm is proposed in 1955 and can be a solution for both indoor and outdoor navigation systems. It is also a shortest path algorithm which is applied for just weighted graphs. In weighted graphs, every edge has a numerical value. Sometimes this numerical values are called cost of the edges and they can not be negative values. All the shortest paths are calculated from a source node to each node which solves the single source shortest path problem. A graph G is composed of a set of nodes/vertices V and and a set of edges E. It's representation is $G=(V,E)$. For the weighted graphs, an edge weight function is represented as $l(v,w)$ which means every vertex v has a positive weight w value. The principle of the algorithm is to set infinity value to the edges when there is no connection between two vertices, and iteration continues till there is no unvisited node left. The calculation starts from the source node i and ends in the destination node j. From i to the nearest node k is stored Dist(k) and iteration continues with the node j. The shortest path i to j is Dist(k)+d(k , j). Weighted graphs can be directed or undirected. The algorithms for directed and undirected graphs are almost same. The difference between them is for the directed graphs connection components can be eligible but for undirected graphs the components are the sum of the edge lengths so they are not eligible.

4.2.1.1 Directed graph example

Node 0 is the start point and from node 0 to node 1, node 2, node 3, node 4, node 5, node 6, and node 7 shown in Figure 4.4. All the shortest paths are calculated by hand and C# programme.

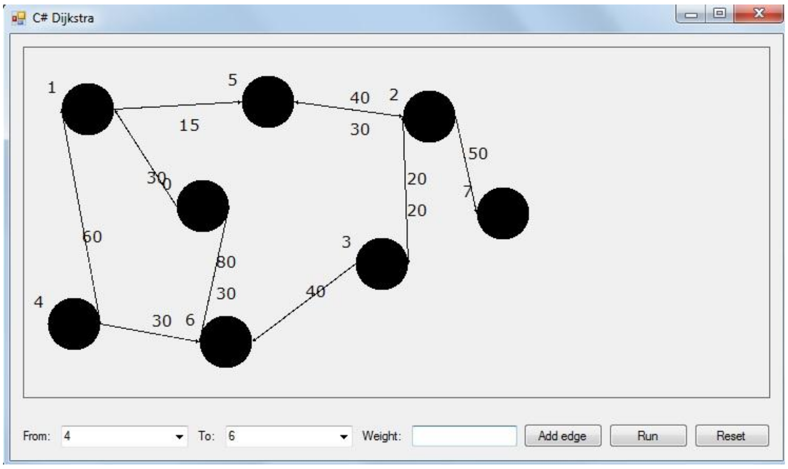

Figure 4.4 : A directed graph with node and edges are shown

In the table 4.1, rows are represented as start points and columns are represented as end point in every iteration. The aim is to calculate the shortest path from node 0 to every single node. In each iteration the lowest node is selected as a start node for the next iteration until all the nodes are visited.

Table 4.1 : Shortest paths from Node 0 to each node in a directed graph, calculated by hand

To From	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7
Node 0	**30**	∞	∞	∞	∞	80	∞
Node 1	30	∞	∞	∞	**45**	80	∞
Node 5	30	85	∞	∞	45	**80**	∞
Node 6	30	**85**	∞	∞	45	80	∞
Node 2	30	85	**105**	∞	45	80	135
Node 3	30	85	105	∞	45	80	**135**
Node 7	30	85	105	∞	45	80	135

In Figure 4.5, shortest paths from node 0 to each node calculated by C# programme.

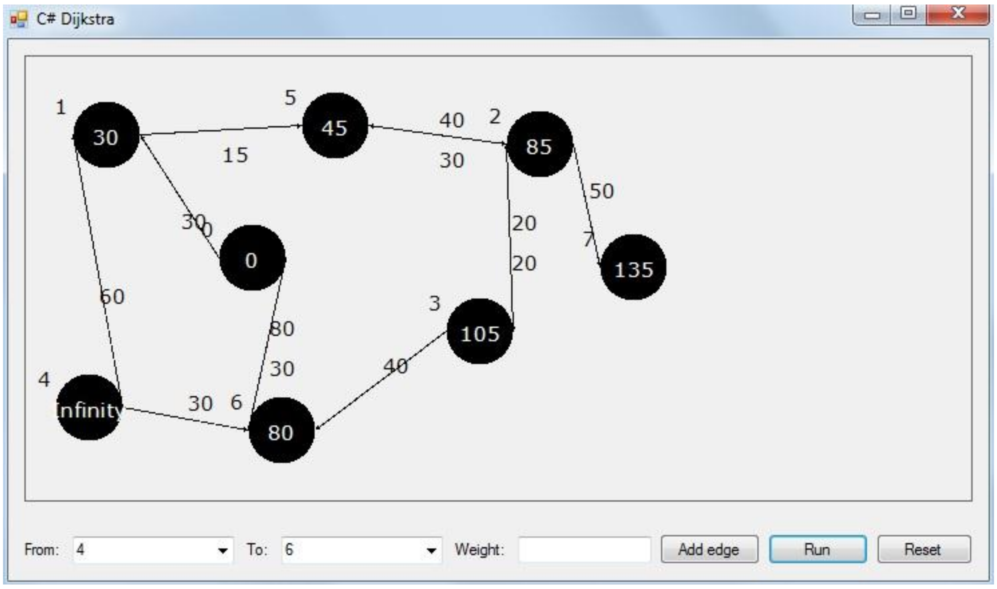

Figure 4.5 : Shortest paths from Node 0 to each node in a directed graph, calculated by C#

4.2.1.2 Undirected graph example

Node0 is the start point and from node 0 to node1, node2, node3, node4, node5, node6, and node7 shown in Figure 4.6. All the shortest paths are calculated by hand and C# programme.

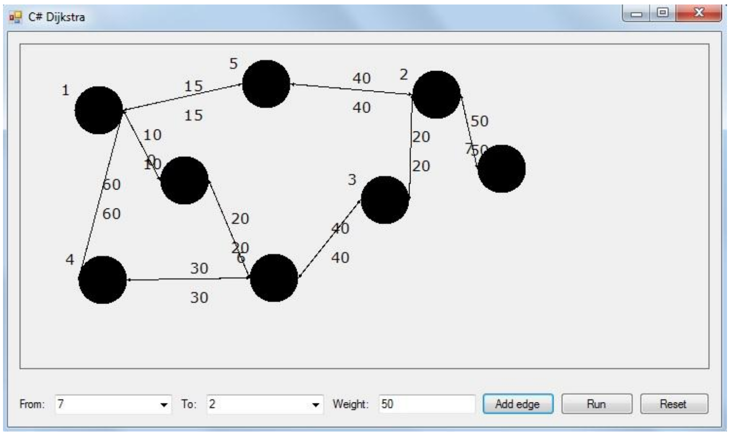

Figure 4.6 : An undirected graph with node and edges are shown

In the table 4.2, rows are represent start points and columns are represent end points in every iteration.

Table 4.2 : Shortest paths from Node 0 to each node in an undirected graph, calculated by hand

To From	Node 1	Node2	Node 3	Node 4	Node 5	Node 6	Node 7
Node 0	**10**	∞	∞	∞	∞	20	∞
Node 1	10	∞	∞	70	25	**20**	∞
Node 6	10	∞	60	50	**25**	20	∞
Node 5	10	65	60	**50**	25	20	∞
Node 4	10	65	**60**	50	25	20	∞
Node 3	10	**65**	60	50	25	20	∞
Node 2	10	65	60	50	25	20	115

Node 0 is the source node and it has connection with just two nodes (Node 1 and Node 6) takes the weight 30 and 80 as implied by the distance between them and the rest of the nodes take infinity because they are not connected with Node 0 directly. In the next step, the lowest weight node is selected as the start node which is Node 1 for this example. From Node 1 there is only one connection that is Node 5. In third step the lowest weight is Node 5 so it is selected as a start node. The iteration keeps going till the all nodes are checked as a start node in Figure 4.7.

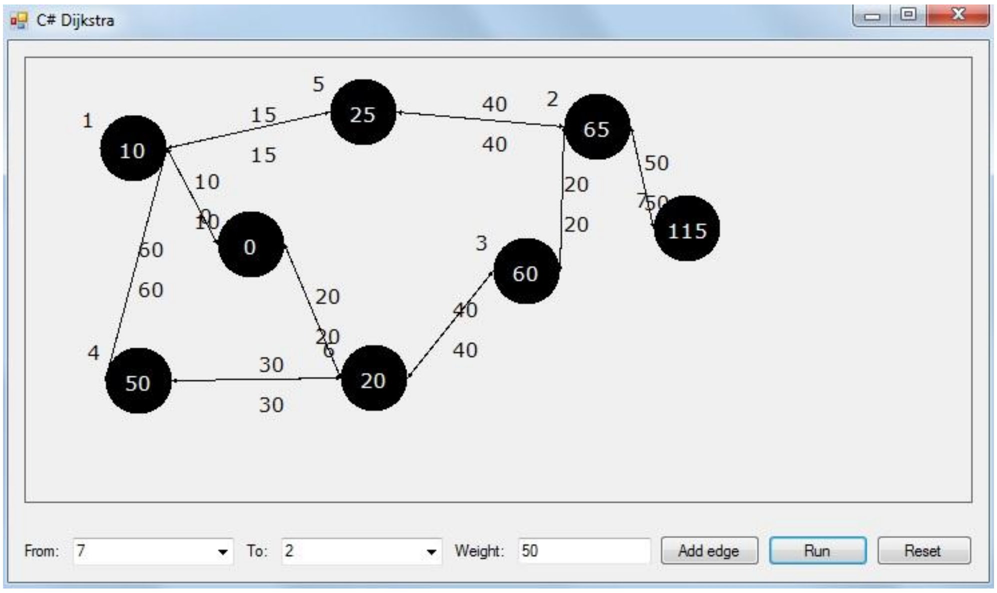

Figure 4.7: Shortest paths from Node 0 to each node in an undirected graph, calculated by C#

4.2.2 Simplest path algorithm

The shortest path is the path that has minimal length but sometimes it can be a complex route description. In such situations, often what is required is not the shortest route to a destination, but the simplest route, in terms of how easy to explain, understand, memorize, or execute the navigation instructions for the route (Duckham & Kulik). Simplest paths can be longer or equal to least risk path because weight is not just depend on the path length also it depends on the edges at each decision point.

4.2.3 Least risk path algorithm

Another optimal path algorithm for indoor spaces is least risk path algorithm. The aim of the least risk path algorithm is to minimize the risk of getting lost. The least risk path algorithm described by Grum (2005) calculates the path between two points where a wayfinder has the least risk of getting lost by selecting all edges and intersections with a minimal risk value. This risk value is measured at every intersection and its defined by the cost for taking a wrong decision at that intersection. The algorithm assumes that (1) the person taking the path is is unfamiliar with its enviroment, and (2) when taking a wrong path segment, the wayfinder notices this immediately and turns back at the next intersection (Grum, 2005). Additional to shortest path, the risk value is added to the path length and a new weight is calculated.

$$Total\_Risk(p) = \sum PathLengths + \sum RiskValue(i) \qquad (4.1)$$

$$RiskValue(i) = \frac{2 * \sum PathLength\_Wrong\_Choices}{No\_Possible\_Choices} \qquad (4.2)$$

The formula for the calculation of the risk value at intersection *i* and the and the total risk of an entire path *p*.

5. IMPLEMENTATION

The test building is the “Plateau-Rozier” which is the faculty of engineering of the Gent University. The building is complex enough to be the test area and the Geometrical Network Model was already known from the previous studies in that building. It was transformed from AutoCAD software to ArcGIS software. In Figure 5.1, ground floor plan and first floor plan of the building shown in ArcGIS software. The black nodes (GIS nodes) are representing the centre of the rooms, black lines (GIS edges) are representing the connection between the nodes and tan colored polygons (GIS rooms) are representing the indoor space. This representation is a network visualizations of the floor plans.

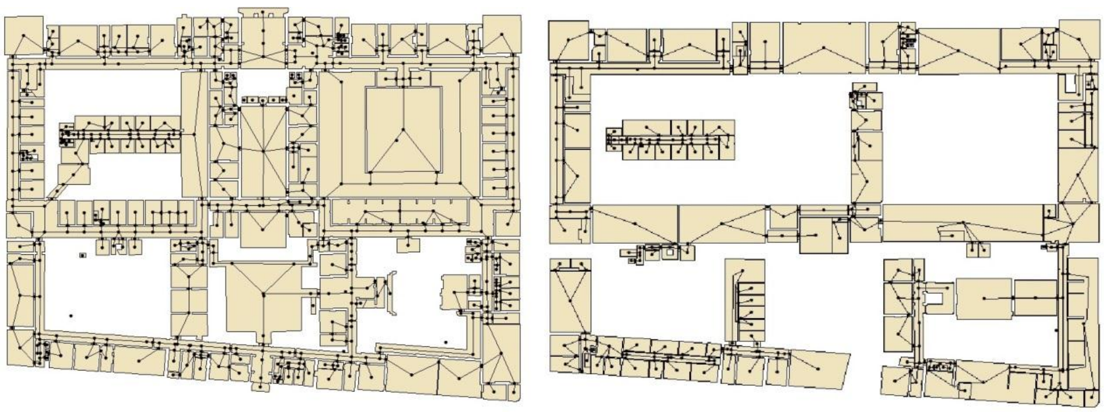

Figure 5.1 : Floor plan of the ground and first floor of the “Plateau-Rozier” building with network visualization

Basically, in the database there are rooms, corridors and stairs/elevators. Rooms are represented as nodes, corridors are transformed to linear features. Stairs and elevators are just connectors that the capacity and the length of them does not considered. In this study, stairs and elevators taken account 3 meters as a constant value. First of all, a ready algorithm is taken from an online source (PWBot) and developed in C# programme. For the shortest path, the algorithm uses the single source shortest path algorithm which is Dijkstra’s algorithm. In this algorithm, weight values are equal to the GIS edges which means length between two nodes. But in least risk path algorithm, weight is not just depend on the length of the edge, it also depends on the risk value at every intersection. The algorithmic structure of least risk path algorithm is similar to Dijkstra's with a continuous loop over all nodes including three consecutive steps:

1. Detect the next smallest node
2. Change the selected node to the next smallest node
3. Adjust the cost values for adjacent nodes

Its only the third step that the least risk path differs from the Dijkstra's algorithm since the cost value is not only based on the length of the edge but also on the risk value of each intersections that is passed. This risk value is dependent on the previous route taken to reach the selected node and the length of its adjacent edges. The following steps in the "adjust cost section" are consecutively executed:

1. Calculate the number of edges leaving from selected node and select each edge successively
2. Two options:

    2.1. Endnode of selected edge has not been selected:

    -Calculate possible total risk values for endnode based on all possible routes arriving in selected node

    -Store the minimum value by comparing it with the currently stored value

    2.2. Endnode of selected edge has been selected but adjacent nodes have not been selected:

    -Calculate the number of edges leaving from endnode and select each edge successively

    -Calculate total risk values for endnode based on all possible routes arriving in selected node and the connection between the selected node and its adjacent node

    -Store the minimum value by comparing it with the currently stored value (Vanclooster & Maeyer)

In the Figure 5.2, red circle is an example of a decision point, the red line represents the way where user came from, the green line represents the way where user supposed to go and the two black lines represents the ways that user can choose wrongly.

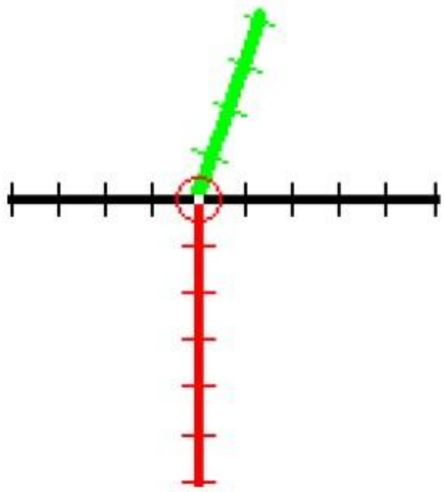

Figure 5.2 : An intersection example (Grum, 2005)

In this example, the risk value is calculated for three points with the least risk path formula and the one that has the minimum value is selected as an current start node. The calculation is made for all the nodes to determine the weight values for the least risk path. Than an excel sheet is prepared with all nodes and their weights plus all the connectors (stairs&elevators). After the excel sheet imported to the C# programme through the excel loader in Figure 5.3.

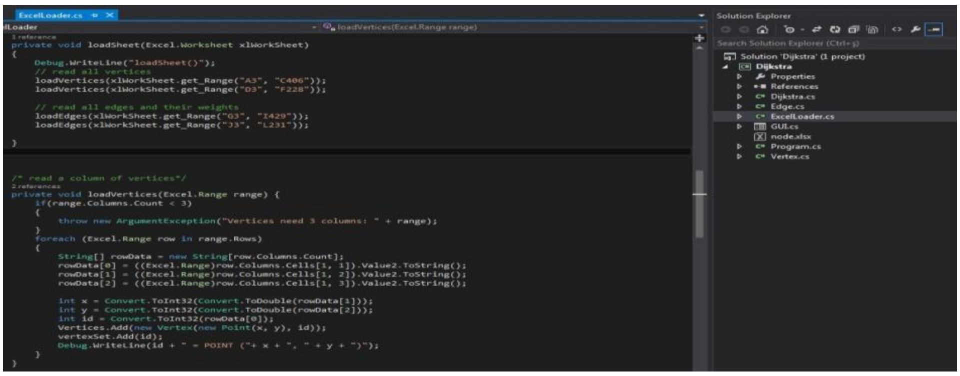

Figure 5.3 : A part of algorithm developed for the excel loader in C# programme

When the nodes and weights are loaded, the source node and end node is chosen and shortest path from that two points is calculated by programme and from the console all the nodes on the path is shown and also the time of calculation. After the six routes are selected for the survey. These selected routes are the ones that the shortest paths and least risk paths are differ from each other maximum on the basis of lenght. In Table 5.1, SourceNode column mean the start node of the path, NodeID column mean the destination node of the path, LenghtDiff(cm) column mean the lenght difference between shortest path and least risk path in the selected route. The routes are chosen according to the highest lenght difference because these are the paths where shortest path and least risk path significantly visually differs from each other.

Table 5.1 : An excel table shows six routes where the shortest path and least risk path differs from each other max

	A	B	C
1	SourceNode	NodeID	LenghtDiff(cm)
2	29	1103	-5116,5
3	175	1104	-5786,5
4	596	1103	-5381,9
5	598	1048	-7449,5
6	612	1103	-5241,8
7	646	1256	-7105,5

After determining these six routes, they are drawn in ArcGIS programme. In the following step, the ground floor and first floor are digitized in Sketch Up programme in 2D and in 3D types of visualizations. Both 2D and 3D visualizations has two options color and black&white.

Figure 5.4 : An example of a 2D visualizations with black&white and color option

In Figure 5.4, S is the starting point and E is the end point. On the left side, there is a black&white visualization and on the right side there is color visualization. Both starts from the same point and ends in the same point. Red lines represents the shortest path and blue lines represents the least risk path. Connection between floors is provided by stairs and elevators. They are just connectors, the capacity does not taken in account in this study. In Figure 5.5, there are two types of 3D vizualizations, the difference comes from their point of views with their black&white and color options.

Figure 5.5 : An example for 3D visualization with black&white and color option

After all the visualizations completed, there are one type of 2D visualization with black&white and color, two types of 3D visualizations with their black&white and color option on the hand. That brings six different visualization option which means nine useful comparison. Since people tend to choice for he left option, another nine pairwise is made by only switching the left-right positions of the visualizations in Table 5.2. At the end, there are 18 different pairwise and 3 main different questions for the survey.

Table 5.2 : There are 18 possible combinations for the survey

	left	right		route	Question
1	2D_BW	2D_C	BW vs C	1	Shortest
2	3D_V1_BW	3D_V1_C		2	Shortest
3	3D_V2_BW	3D_V2_C		3	Shortest
4	2D_BW	3D_V1_BW	Only BW	4	Simplest
5	2D_BW	3D_V2_BW		5	Simplest
6	3D_V1_BW	3D_V2_BW		6	Simplest
7	2D_C	3D_V1_C	Only C	1	Fewest t
8	2D_C	3D_V2_C		3	Fewest t
9	3D_V1_C	3D_V2_C		5	Fewest t

	left	right		route	Question
10	2D_C	2D_BW	BW vs C	6	Simplest
11	3D_V1_C	3D_V1_BW		5	Simplest
12	3D_V2_C	3D_V2_BW		4	Simplest
13	3D_V1_BW	2D_BW	Only BW	3	Fewest t
15	3D_V2_BW	2D_BW		2	Fewest t
15	3D_V2_BW	3D_V1_BW		1	Fewest t
16	3D_V1_C	2D_C	Only C	6	Shortest
17	3D_V2_C	2D_C		4	Shortest
18	3D_V2_C	3D_V1_C		2	Shortest

Its aimed to enable different point of views to the users. This allows us to have 18 different tasks. The survey is prepared in limesurvey and after a personal information page, there are 18 pages. In each page there are four questions, but totally there are six types of questions in the survey.

1. Which route is the shortest?
2. Which route is the simplest?
3. Which route has the fewest turns?
4. On which visualizations did you base your conclusion most?
5. Which visualization do you prefer for solving a routing problem?
6. Which visualization do you prefer from an esthetical point of view?

The survey is filled by 50 people and all of them were unfamiliar to the building. 17 people were Turkish and between the age 22-58 and 12 of them were bachelor. 33 of the people were foreigners that 31 of them are from Europe and the age scale is between 24-32 and 19 of them are bachelor. According to the survey results, 60% of the people prefer shortest path and 86% of the people find 2D visualisation easier to understand that most of them did their conclusion based on 2D visualization. Also they find it more esthetical and see it as a solution for a routing problem.

6. CONCLUSION

The aim of this study is to compare two cognitive algorithms that can be applied indoor spaces. These algorithms are Dijkstra's algorithm and least risk path algorithm. For this purpose, the general information about indoor positioning techniques and the combination of these techniques are explained with their limitations. Then, the modelling techniques for indoor spaces are explained in details. For the implementation, a survey is prepared in LimeSurvey which is an online platform to prepare questionnary. 18 different visualization are prepared and are asked to 50 users in Appendix A. As a result, the people who are unfamiliar to the indoor space, they mostly choose 2D visualization because they find it easier to understand. Also most of the people find 3D visualization more esthetical but complicated to understand. From another point of view, this study again approved that the least risk path can be longer than shortest path but the risk values in the intersections are less than shortest path. And this risk values are depend on the length of the edges which can be wrong. For a future research the existing optimal routes can be developed by adding more parameters and some new algorithms can be discovered as a solution for the user requirements. Also the results can be classified by the users or different navigation devices that used for navigation such as cell phones etc. Different levels of visualizations, different color visualizations such as black&white and color can be another research subjects.

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Url-3<*http://pwbot.googlecode.com/svn-history/r41/trunk/Bot/Dijkstra.cs*>,date retrieved 20.10.2014.

Url-4 *https://www.qualcomm.com/*, date retrieved 03.10.2014.

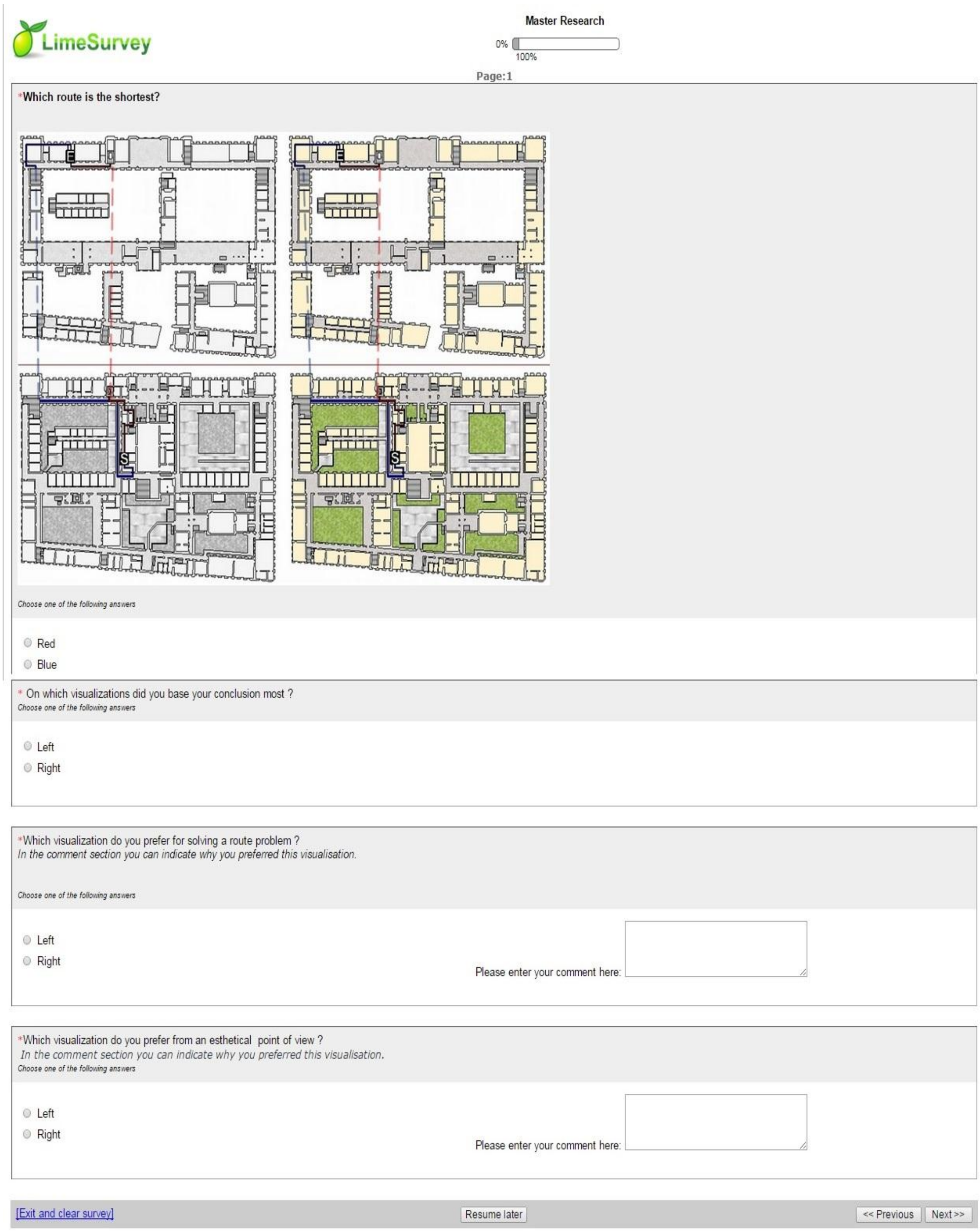
APPENDICES

APPENDIX A: Survey prepared in LimeSurvey

APPENDIX B: Dijksta’s algorithm taken from online source (Url-3)

APPENDIX C: Excel Loader developed in C#

APPENDIX A


Master Research

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Page:1

*Which route is the shortest?

Choose one of the following answers

Red

Blue

* On which visualizations did you base your conclusion most ?

Choose one of the following answers

Left

Right

*Which visualization do you prefer for solving a route problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

Left

Right

Please enter your comment here:

*Which visualization do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

Left

Right

Please enter your comment here:

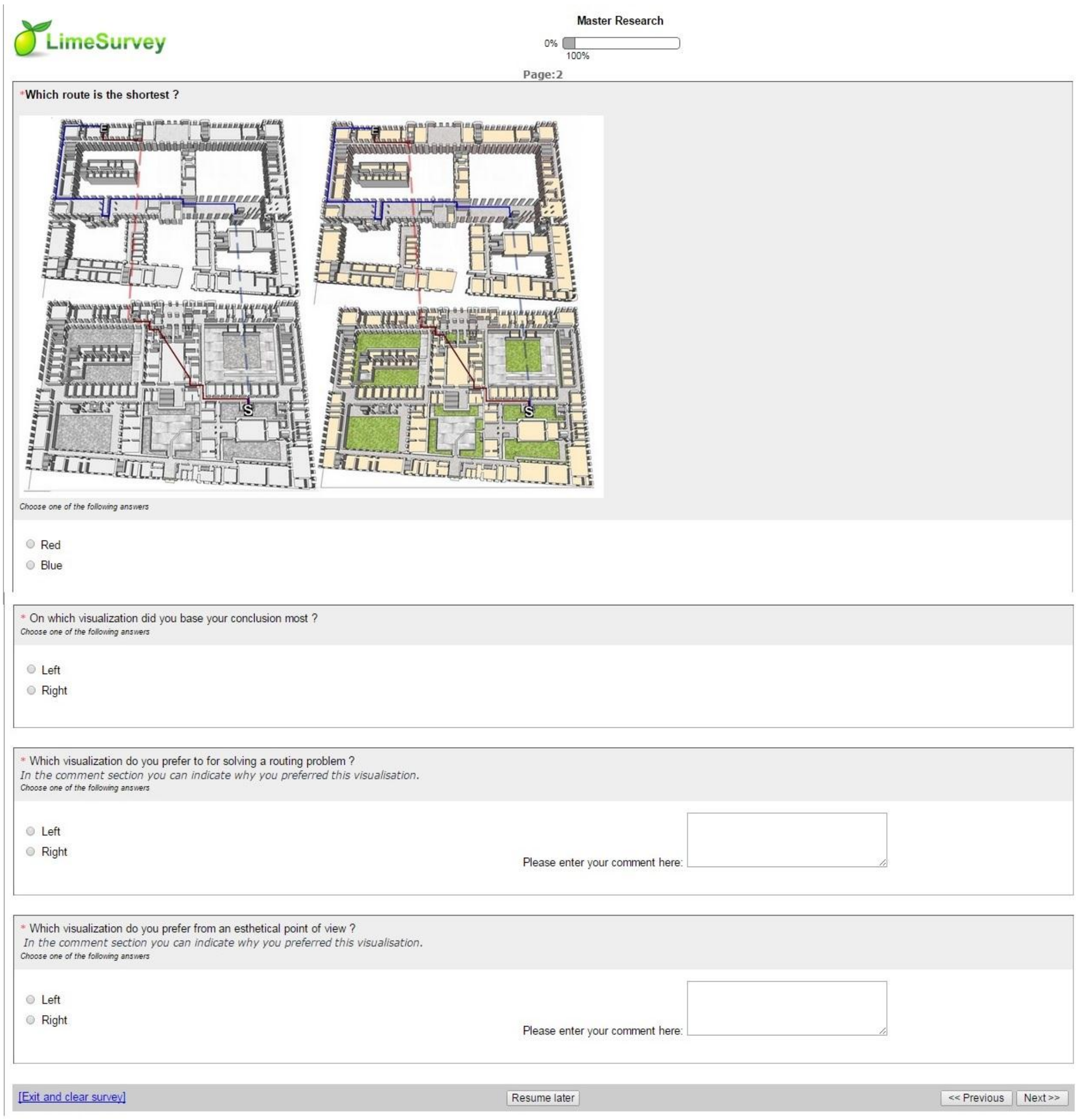
[Exit and clear survey]

Resume later

<< Previous

Next >>

Figure A.1: Page 1



LimeSurvey

Master Research

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Page:2

*Which route is the shortest ?

Choose one of the following answers

- Red
- Blue

* On which visualization did you base your conclusion most ?

Choose one of the following answers

- Left
- Right

* Which visualization do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

* Which visualization do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

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Figure A.2: Page 2

LimeSurvey

Master Research

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Page:3

*Which route is the shortest ?

Choose one of the following answers

- Red
- Blue

* On which visualization did you base your conclusion most ?

Choose one of the following answers

- Left
- Right

* Which visualization do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

* Which visualization do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

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Figure A.3: Page 3

LimeSurvey

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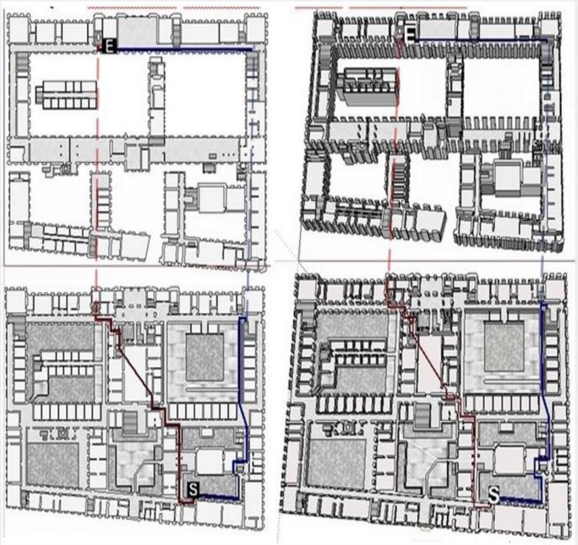
Page:4

*Which route is the simplest ?



Choose one of the following answers

- Red
- Blue

* On which visualization did you base your conclusion most ?

Choose one of the following answers

- Right
- Left

* Which visualization do you prefer to for solving a route problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

* Which visualization do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

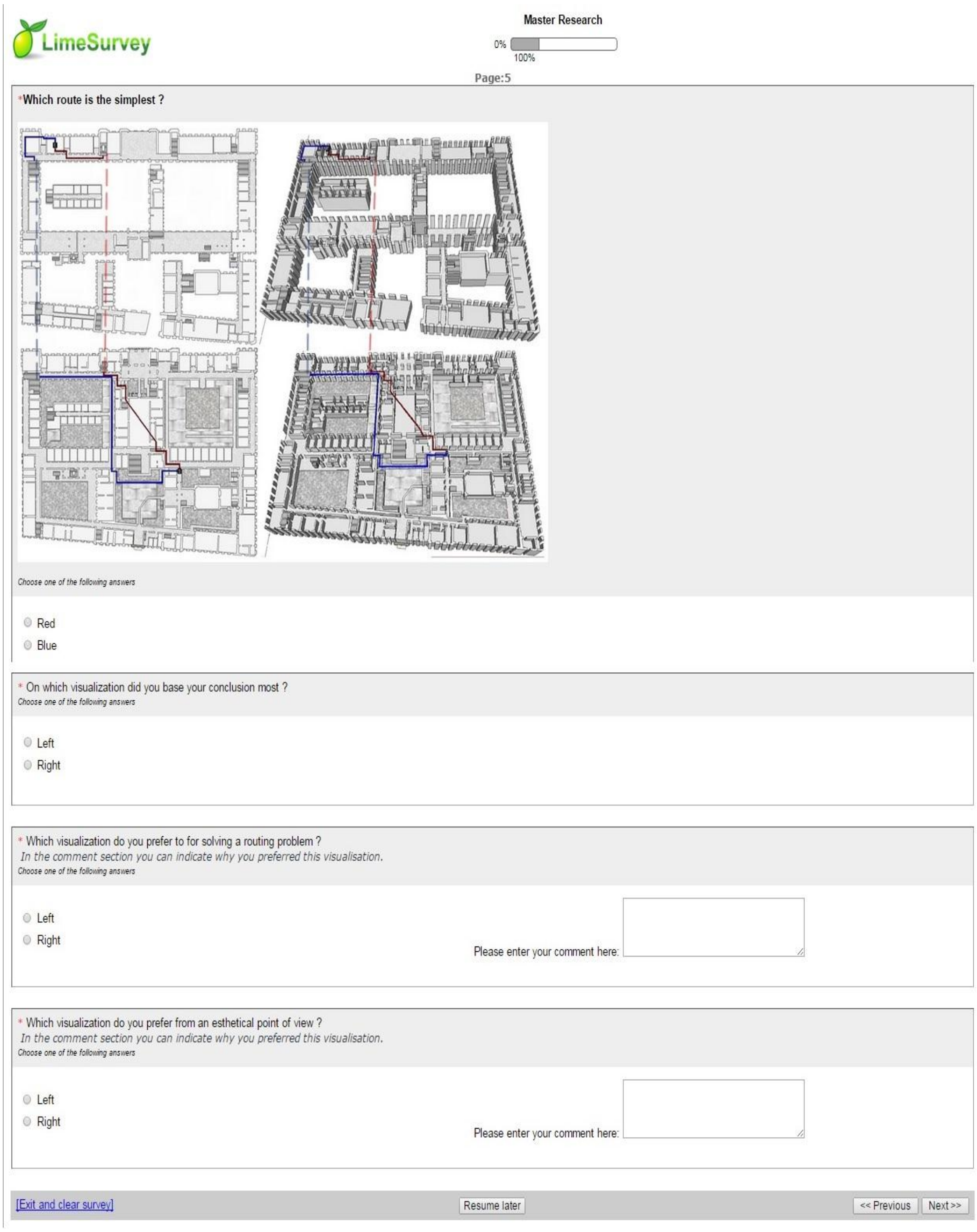
Choose one of the following answers

- Left
- Right

Please enter your comment here:

[Exit and clear survey] Resume later << Previous Next >>

Figure A.4: Page 4



LimeSurvey

Master Research

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Page:5

*Which route is the simplest ?

Choose one of the following answers

○ Red
○ Blue

* On which visualization did you base your conclusion most ?
Choose one of the following answers

○ Left
○ Right

* Which visualization do you prefer to for solving a routing problem ?
In the comment section you can indicate why you preferred this visualisation.
Choose one of the following answers

○ Left
○ Right

Please enter your comment here:

* Which visualization do you prefer from an esthetical point of view ?
In the comment section you can indicate why you preferred this visualisation.
Choose one of the following answers

○ Left
○ Right

Please enter your comment here:

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Figure A.5: Page 5

LimeSurvey

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Page:6

*Which route is the simplest ?

Choose one of the following answers

- Red
- Blue

* On which visualization did you base your conclusion most ?

Choose one of the following answers

- Left
- Right

* Which visualization do you prefer to for solving a route problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

* Which visualization do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

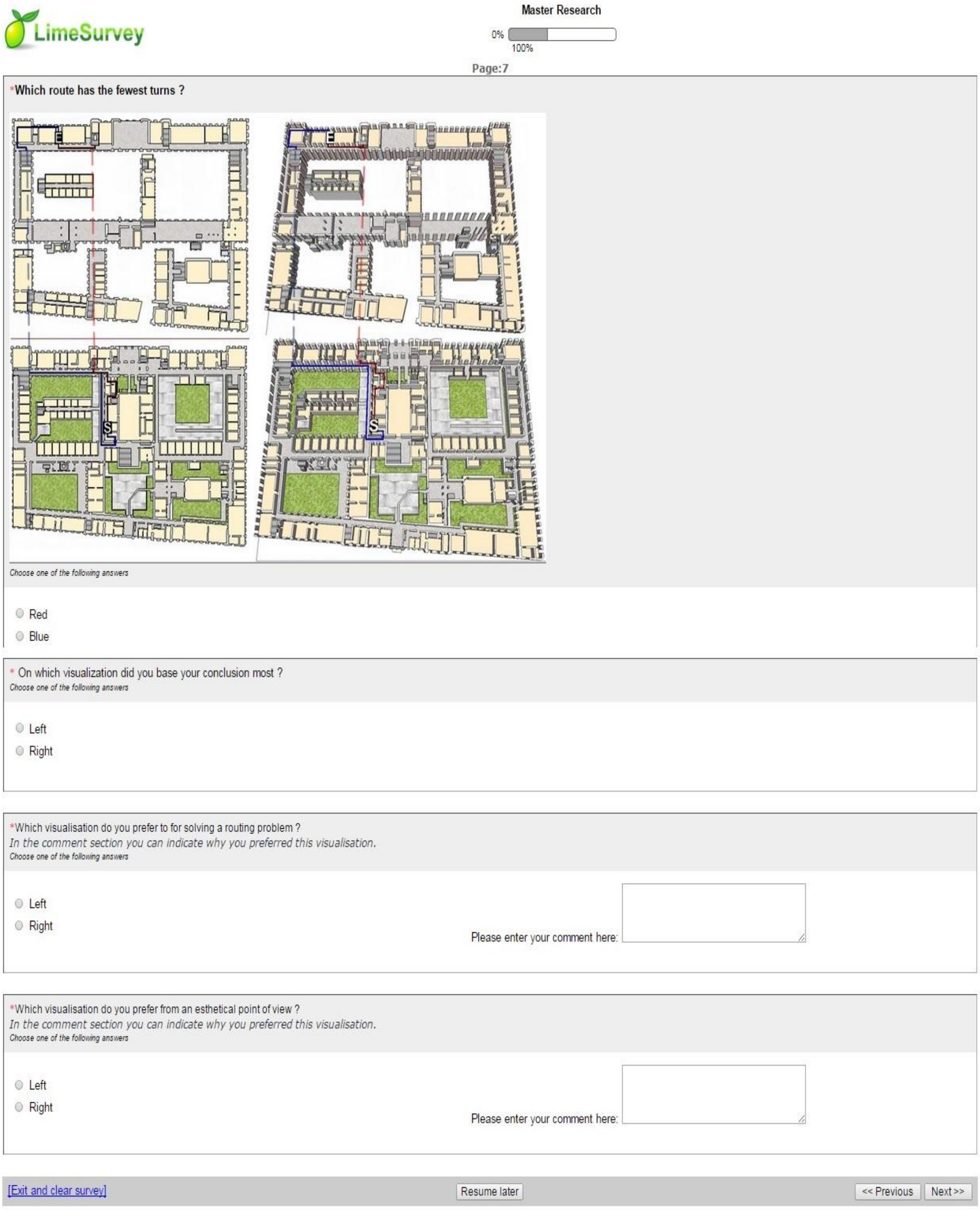
Choose one of the following answers

- Left
- Right

Please enter your comment here:

[Exit and clear survey] Resume later << Previous Next >>

Figure A.6: Page 6



LimeSurvey

Master Research

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Page:7

*Which route has the fewest turns ?

Choose one of the following answers

Red

Blue

* On which visualization did you base your conclusion most ?

Choose one of the following answers

Left

Right

*Which visualisation do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

Left

Right

Please enter your comment here:

*Which visualisation do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

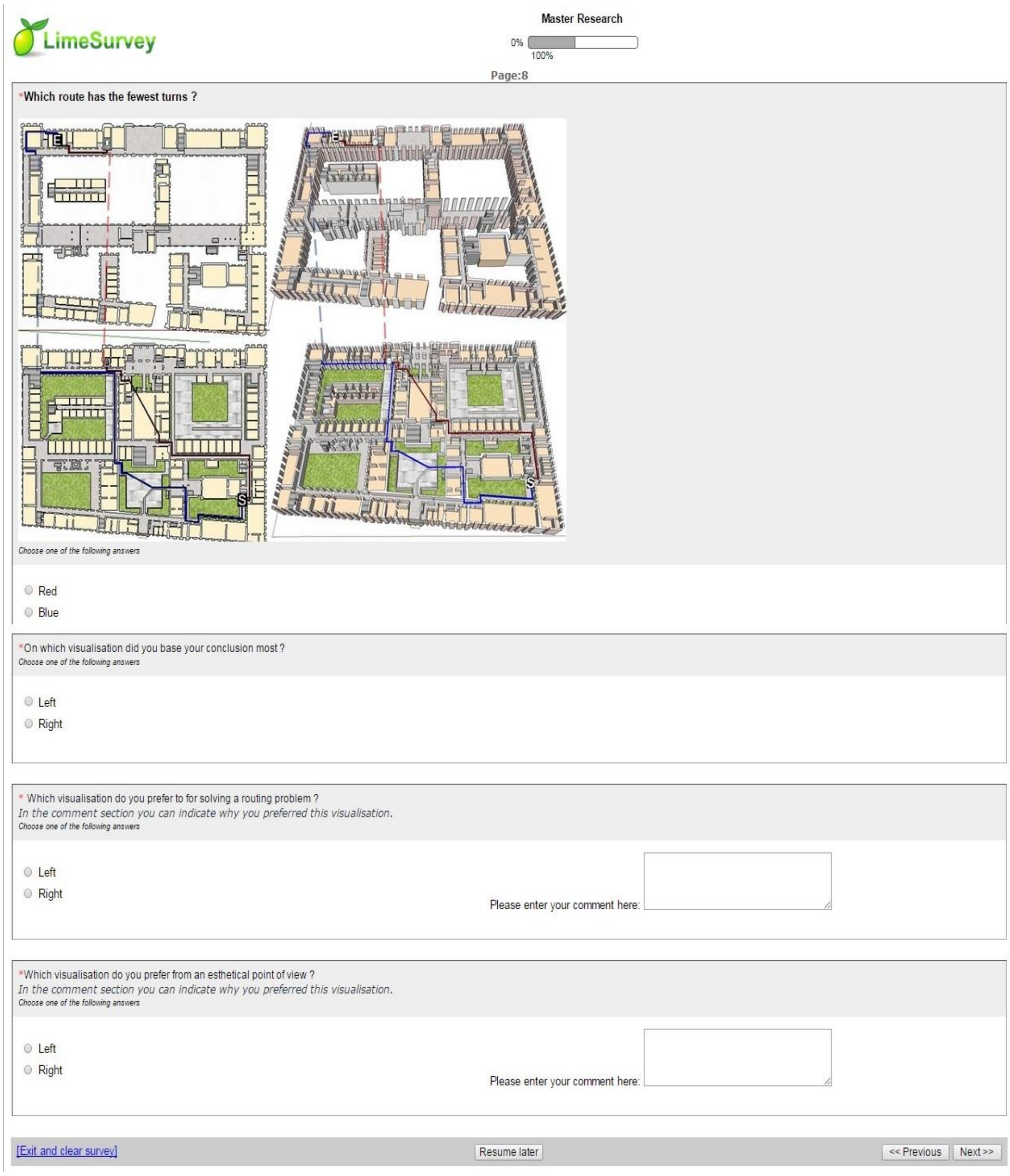
Left

Right

Please enter your comment here:

[Exit and clear survey] Resume later << Previous Next >>

Figure A.7: Page 7



LimeSurvey

Master Research

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Page:8

*Which route has the fewest turns ?

Choose one of the following answers

- Red
- Blue

*On which visualisation did you base your conclusion most ?

Choose one of the following answers

- Left
- Right

* Which visualisation do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

*Which visualisation do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

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Figure A.8: Page 8

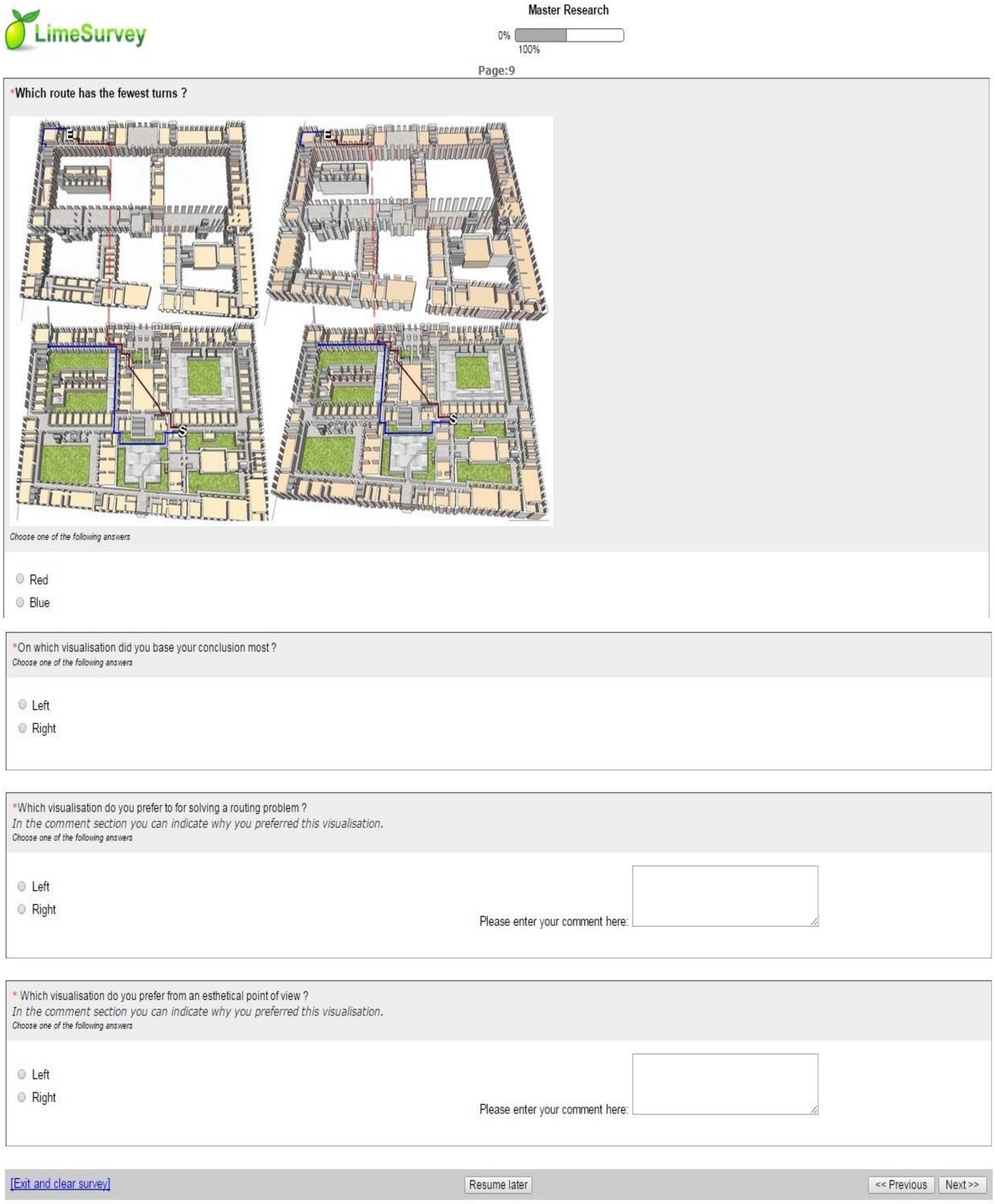

Figure A.9: Page 9

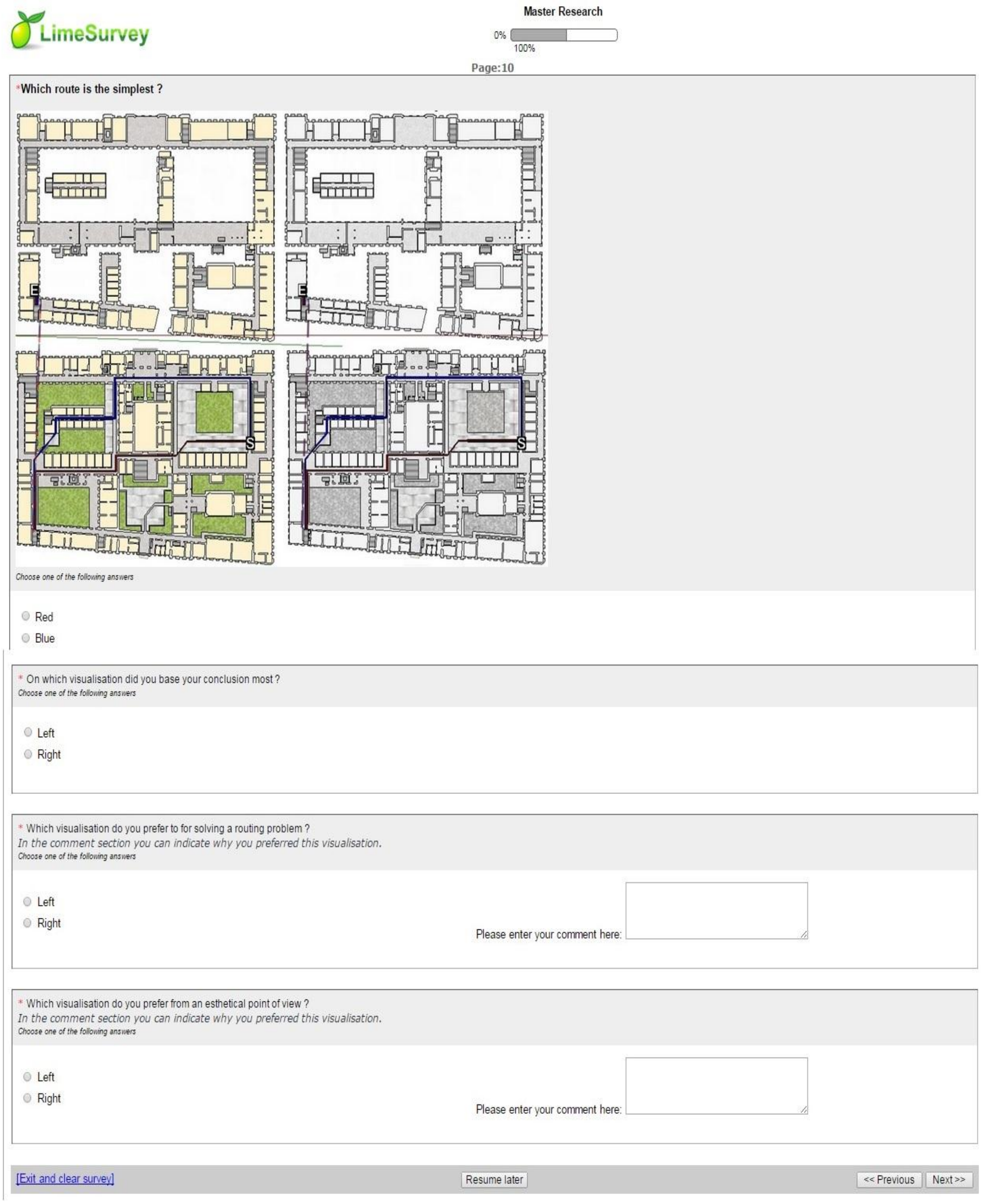

Figure A.10: Page 10

LimeSurvey

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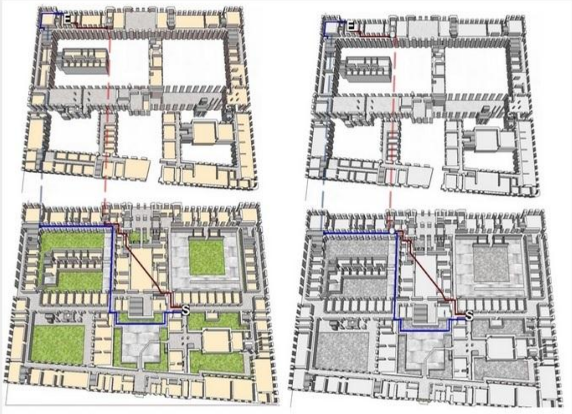
Page: 11

*Which route is the simplest ?



Choose one of the following answers

- Red
- Blue

* On which visualisation did you base your conclusion most ?

Choose one of the following answers

- Left
- Right

* Which visualisation do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

* Which visualisation do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

[Exit and clear survey] Resume later << Previous Next >>

Figure A.11: Page 11


LimeSurvey

Master Research

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Page:12

*Which route is the simplest ?

Choose one of the following answers

Red

Blue

* On which visualisation did you base your conclusion most ?

Choose one of the following answers

Left

Right

* Which visualisation do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

Left

Right

Please enter your comment here:

* Which visualisation do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

Left

Right

Please enter your comment here:

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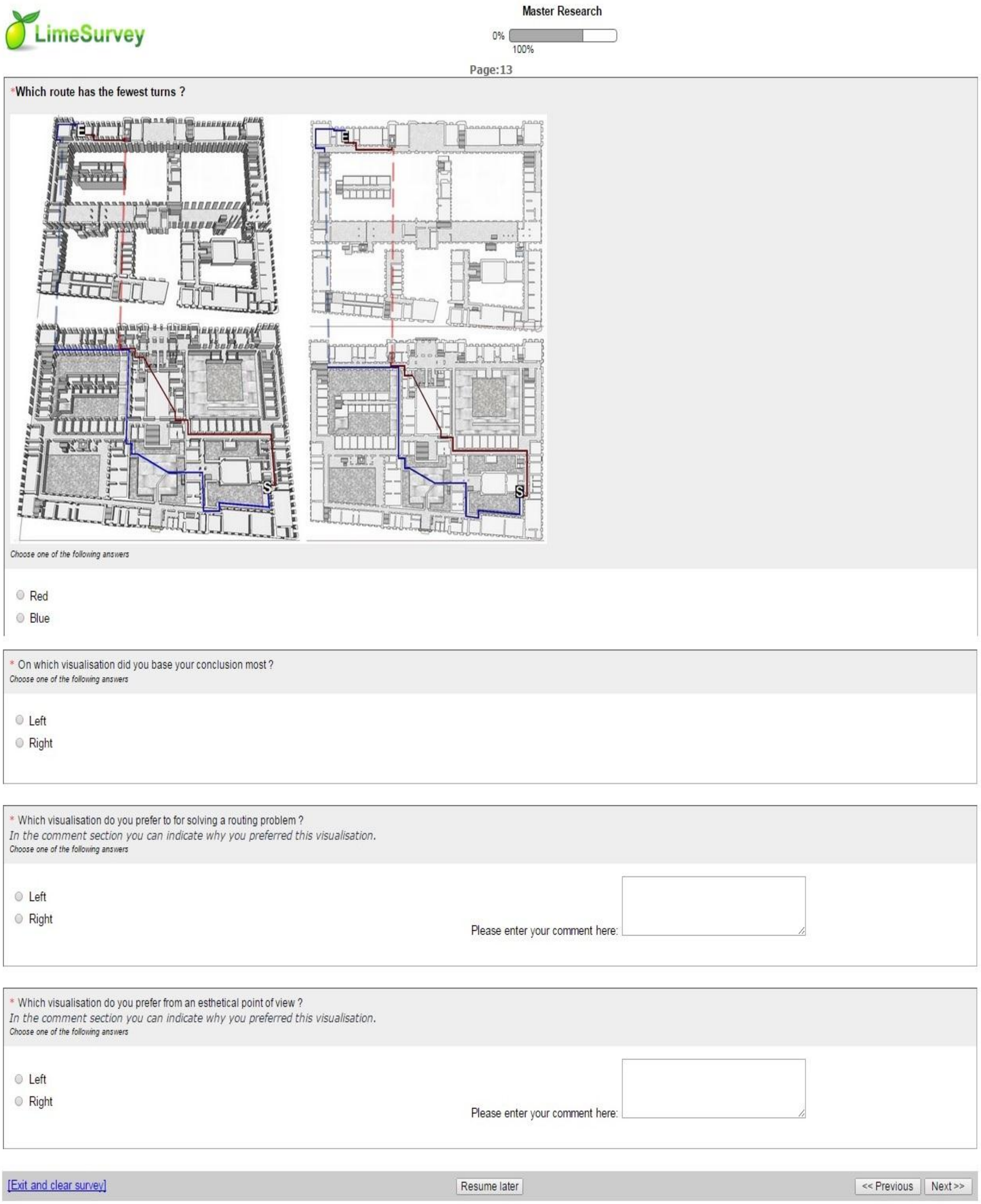
Figure A.12: Page 12



LimeSurvey

Master Research

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Page:13

*Which route has the fewest turns ?

Choose one of the following answers

- Red
- Blue

* On which visualisation did you base your conclusion most ?

Choose one of the following answers

- Left
- Right

* Which visualisation do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

* Which visualisation do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

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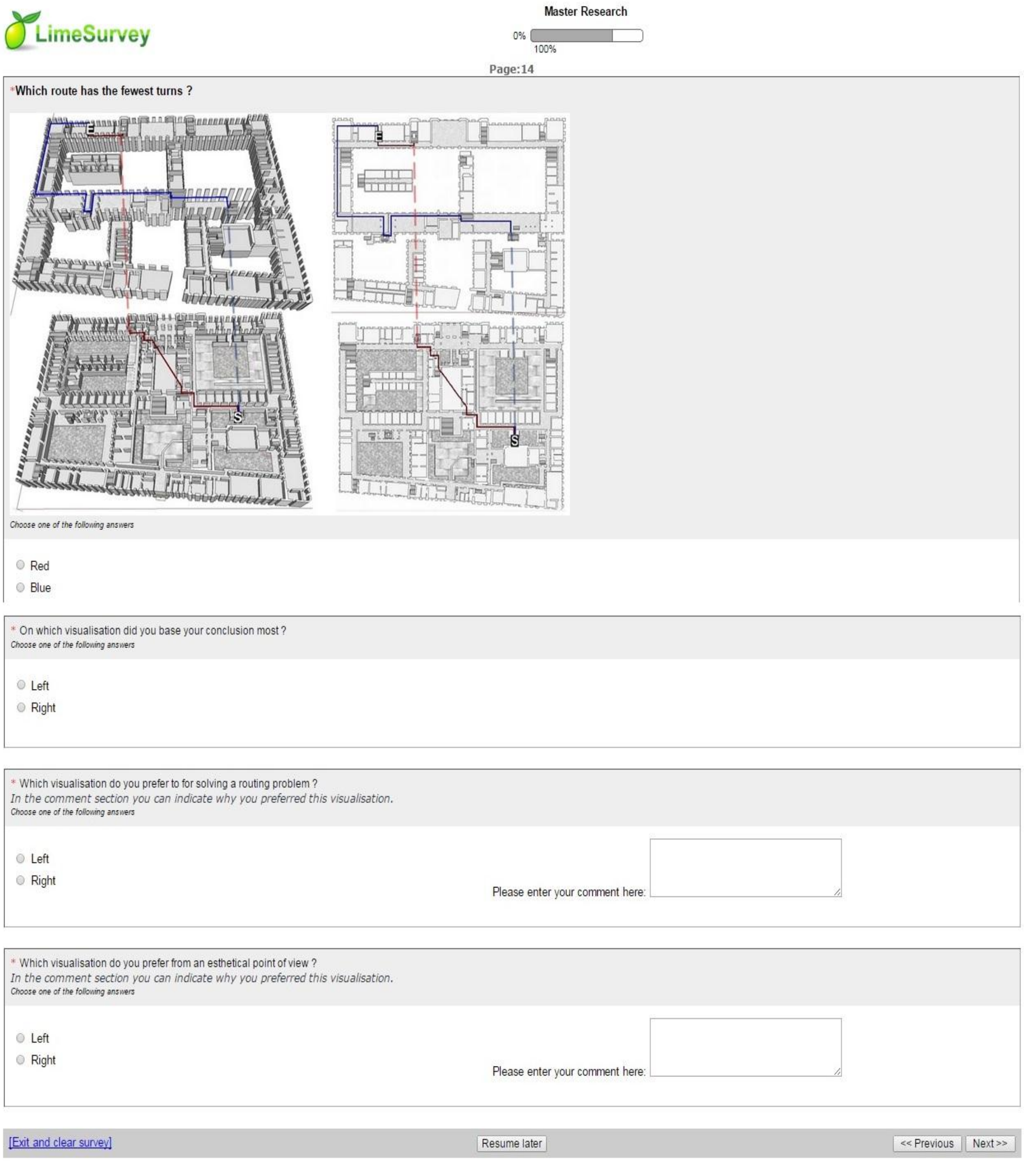
Figure A.13: Page 13



LimeSurvey

Master Research

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Page: 14

*Which route has the fewest turns ?

Choose one of the following answers

- Red
- Blue

* On which visualisation did you base your conclusion most ?

Choose one of the following answers

- Left
- Right

* Which visualisation do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

* Which visualisation do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

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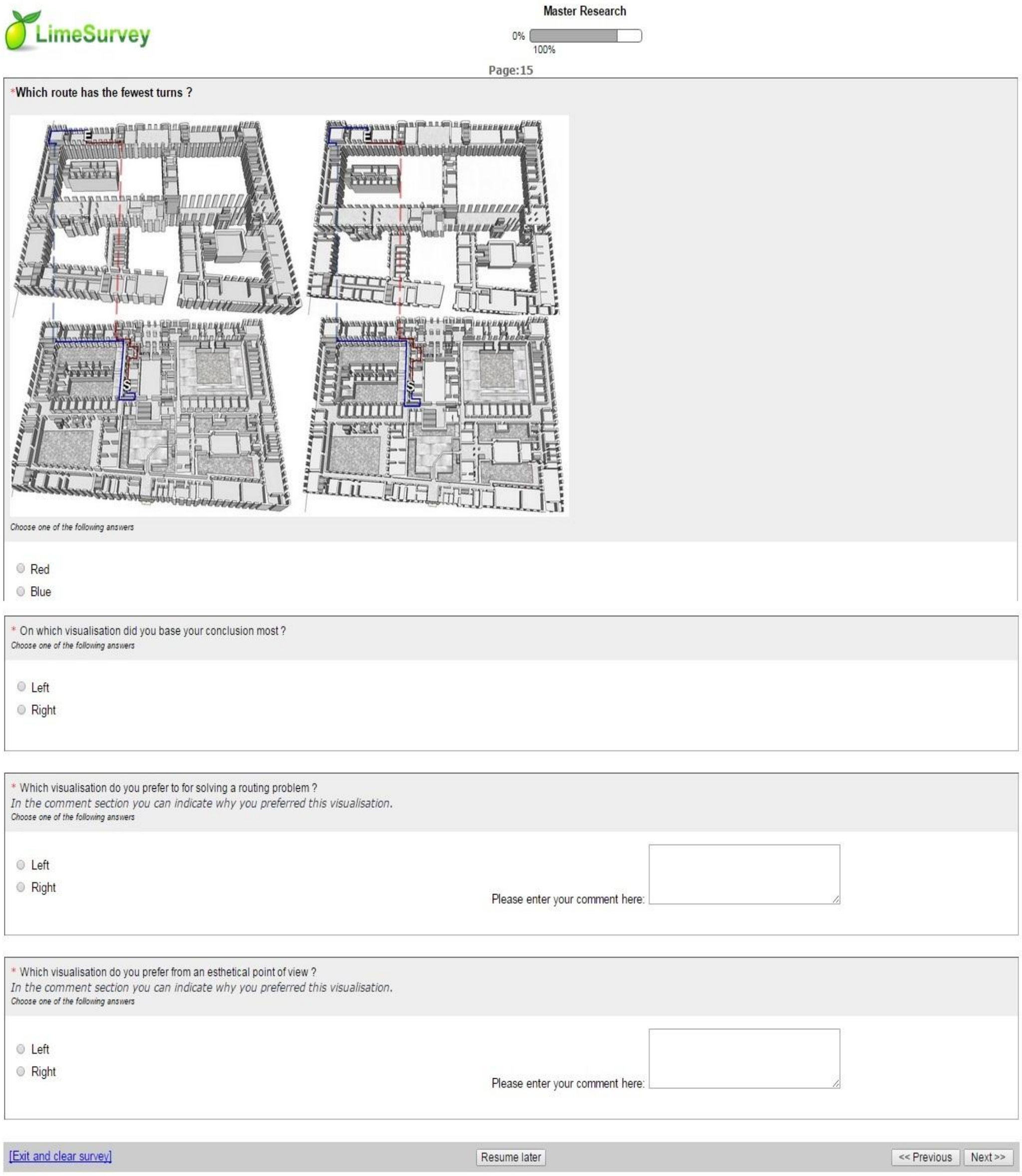
Figure A.14: Page 14


LimeSurvey

Master Research

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Page:15

*Which route has the fewest turns ?

Choose one of the following answers

- Red
- Blue

* On which visualisation did you base your conclusion most ?

Choose one of the following answers

- Left
- Right

* Which visualisation do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

* Which visualisation do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

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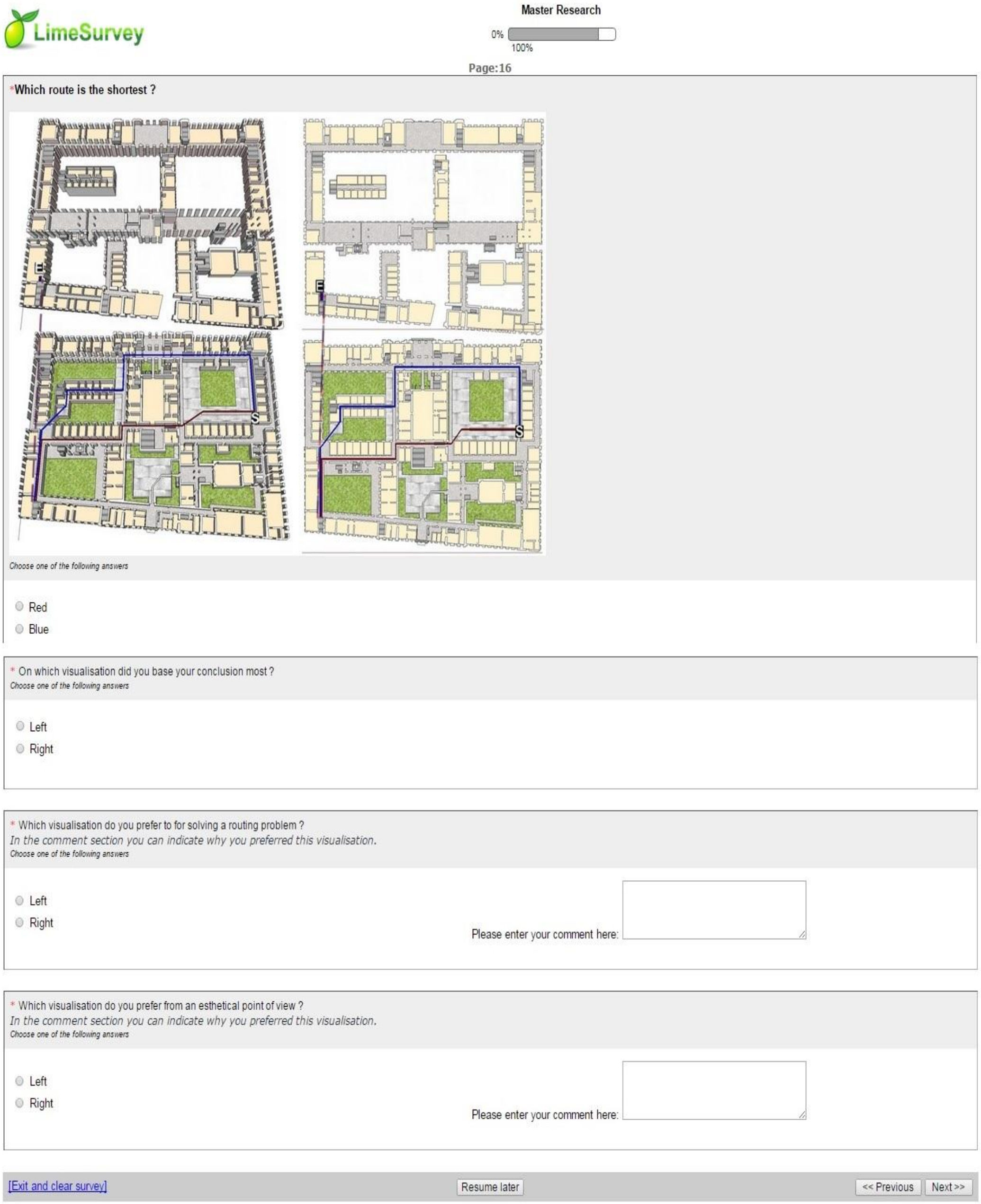
Figure A.15: Page 15


LimeSurvey

Master Research

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Page:16

*Which route is the shortest ?

Choose one of the following answers

Red

Blue

* On which visualisation did you base your conclusion most ?

Choose one of the following answers

Left

Right

* Which visualisation do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

Left

Right

Please enter your comment here:

* Which visualisation do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

Left

Right

Please enter your comment here:

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Figure A.16: Page 16


LimeSurvey

Master Research

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Page:17

*Which route is the shortest ?

Choose one of the following answers

- Red
- Blue

* On which visualisation did you base your conclusion most ?

Choose one of the following answers

- Left
- Right

* Which visualisation do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

* Which visualisation do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

[Exit and clear survey] Resume later << Previous Next >>

Figure A.17: Page 17

Master Research

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Page:18

*Which route is the shortest ?

Choose one of the following answers

- Red
- Blue

* On which visualisation did you base your conclusion most ?

Choose one of the following answers

- Left
- Right

* Which visualisation do you prefer to for solving a routing problem ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

* Which visualisation do you prefer from an esthetical point of view ?

In the comment section you can indicate why you preferred this visualisation.

Choose one of the following answers

- Left
- Right

Please enter your comment here:

[Exit and clear survey] Resume later << Previous Submit

Figure A.18: Page 18

```
class Dijkstra
        {
                /* Takes adjacency matrix in the following format,
for a directed graph (2-D array)
                 * Ex. node 1 to 3 is accessible at a cost of 4
                 *        0  1  2  3  4
                 *   0  { 0, 2, 5, 0, 0},
                 *   1  { 0, 0, 0, 4, 0},
                 *   2  { 0, 6, 0, 0, 8},
                 *   3  { 0, 0, 0, 0, 9},
                 *   4  { 0, 0, 0, 0, 0}
                 */

                /* Resulting arrays with distances to nodes and how
to get there */
                private int[] dist;
                public int[] Dist
                {
                        get { return dist; }
                        private set { dist = value; }
                }

                private int[] path;
                public int[] Path
                {
                        get { return path; }
                        private set { path = value; }
                }

                /* Holds queue for the nodes to be evaluated */
                private readonly List<int> queue = new List<int>();

                /* Sets up initial settings */
                private void Initialize(int start, int len)
                {
                        Dist = new int[len];
                        Path = new int[len];

                        /* Set distance to all nodes to infinity -
alternatively use Int.MaxValue for use of Int type instead */
                        for (int i = 0; i < len; i++)
                        {
                                Dist[i] = int.MaxValue;

                                queue.Add(i);
                        }

                        /* Set distance to 0 for starting point and
the previous node to null (-1) */
                        Dist[start] = 0;
                        Path[start] = -1;
                }

                /* Retrives next node to evaluate from the queue */
                private int GetNextVertex()
                {
                        double min = Double.PositiveInfinity;
                        int vertex = -1;

                        /* Search through queue to find the next
node having the smallest distance */
```

```
                        foreach (int j in queue)
                        {
                                if (Dist[j] <= min)
                                {
                                        min = Dist[j];
                                        vertex = j;
                                }
                        }

                        queue.Remove(vertex);

                        return vertex;
                }

                /* Takes a graph as input an adjacency matrix (see
top for details) and a starting node */
                public Dijkstra(int[,] graph, int start)
                {
                        /* Check graph format and that the graph
actually contains something */
                        if (graph.GetLength(0) < 1 ||
graph.GetLength(0) != graph.GetLength(1))
                        {
                                throw new ArgumentException("Graph
error, wrong format or no nodes to compute");
                        }

                        int len = graph.GetLength(0);

                        Initialize(start, len);

                        while (queue.Count > 0)
                        {
                                int u = GetNextVertex();

                                /* Find the nodes that u connects to
and perform relax */
                                for (int v = 0; v < len; v++)
                                {
                                        /* Checks for edges with
negative weight */
                                        if (graph[u, v] < 0)
                                        {
                                                throw new
ArgumentException("Graph contains negative edge(s)");
                                        }

                                        /* Check for an edge between
u and v */
                                        if (graph[u, v] > 0)
                                        {
                                                /* Edge exists,
relax the edge */
                                                if (Dist[v] >
Dist[u] + graph[u, v])
                                                {
```

Appendix B

```
using System;
using Excel = Microsoft.Office.Interop.Excel;
using System.Windows.Forms;
using System.Collections.Generic;
using System.Drawing;
using System.Diagnostics;

namespace Dijkstra
{
    class ExcelLoader
    {
        HashSet<int> vertexSet;
        private List<Vertex> Vertices;
        private List<Edge> Edges;

        public ExcelLoader()
        {
            vertexSet = new HashSet<int>();
            Vertices = new List<Vertex>();
            Edges = new List<Edge>();
        }

        public void LoadFile(string filename)
        {
            vertexSet.Clear();
            Vertices.Clear();
            Edges.Clear();

            Excel.Application xlApp;
            Excel.Workbook xlWorkBook;
            Excel.Worksheet xlWorkSheet;
            object misValue = System.Reflection.Missing.Value;

            System.Globalization.CultureInfo oldCI =
System.Threading.Thread.CurrentThread.CurrentCulture;
            System.Threading.Thread.CurrentThread.CurrentCulture = new
System.Globalization.CultureInfo("en-US");

            xlApp = new Excel.Application();
            xlWorkBook = xlApp.Workbooks.Open(filename, 0, true, 5, "", "",
true, Excel.XlPlatform.xlWindows, "\t", false, false, 0, true, 1, 0);
            xlWorkSheet =
(Excel.Worksheet)xlWorkBook.Worksheets.get_Item(1);

            loadSheet(xlWorkSheet);
            xlWorkBook.Close(true, misValue, misValue);
            xlApp.Quit();

            releaseObject(xlWorkSheet);
            releaseObject(xlWorkBook);
            releaseObject(xlApp);
            validateData();
        }

        private void validateData()
        {
            foreach (Edge edge in Edges)
            {
                bool containsFrom = vertexSet.Contains(edge.from);
                bool containsTo = vertexSet.Contains(edge.to);
                if (!containsFrom)
                {
```

```
                    throw new ArgumentException("Vertex from: " + edge.from
+ " not found in Edge: <from:" + edge.from + ", to:" + edge.to + ", Length="
+ edge.weight + ">");
                }
                if (!containsTo)
                {
                    throw new ArgumentException("Vertex to: " + edge.to + "
not found in Edge: <from:" + edge.from + ", to:" + edge.to + ", Length=" +
edge.weight + ">");
                }

            }

        }



        private void loadSheet(Excel.Worksheet xlWorkSheet)
        {
            Debug.WriteLine("loadSheet()");
            // read all vertices
            loadVertices(xlWorkSheet.get_Range("A3", "C406"));
            loadVertices(xlWorkSheet.get_Range("D3", "F228"));

            // read all edges and their weights
            loadEdges(xlWorkSheet.get_Range("G3", "I429"));
            loadEdges(xlWorkSheet.get_Range("J3", "L226"));

        }



        /* read a column of vertices*/
        private void loadVertices(Excel.Range range) {
            if(range.Columns.Count < 3)
            {
                throw new ArgumentException("Vertices need 3 columns: " +
range);
            }
            foreach (Excel.Range row in range.Rows)
            {
                String[] rowData = new String[row.Columns.Count];
                rowData[0] = ((Excel.Range)row.Columns.Cells[1,
1]).Value2.ToString();
                rowData[1] = ((Excel.Range)row.Columns.Cells[1,
2]).Value2.ToString();
                rowData[2] = ((Excel.Range)row.Columns.Cells[1,
3]).Value2.ToString();

                int x = Convert.ToInt32(Convert.ToDouble(rowData[1]));
                int y = Convert.ToInt32(Convert.ToDouble(rowData[2]));
                int id = Convert.ToInt32(rowData[0]);
                Vertices.Add(new Vertex(new Point(x, y), id));
                vertexSet.Add(id);
                Debug.WriteLine(id + " = POINT ("+ x + ", " + y + ")");
            }
        }

        /* read a column of edges*/
        private void loadEdges(Excel.Range range)
        {
            if (range.Columns.Count < 3)
```

```
            {
                throw new ArgumentException("Edges need 3 columns");
            }
            foreach (Excel.Range row in range.Rows)
            {
                String[] rowData = new String[row.Columns.Count];
                rowData[0] = ((Excel.Range)row.Columns.Cells[1, 
1]).Value2.ToString();
                rowData[1] = ((Excel.Range)row.Columns.Cells[1, 
2]).Value2.ToString();
                rowData[2] = ((Excel.Range)row.Columns.Cells[1, 
3]).Value2.ToString();

                int from = Convert.ToInt32(Convert.ToDouble(rowData[0]));
                int to = Convert.ToInt32(Convert.ToDouble(rowData[1]));
                double weight = Convert.ToDouble(rowData[2]);
                Edges.Add(new Edge(from, to, weight)); ;
                Debug.WriteLine("EDGE (from: " + from + ", to: " + to + ") = 
Length: " + weight);
            }
        }

        public List<Vertex> getVertices()
        {
            return Vertices;
        }

        public List<Edge> getEdges()
        {
            return Edges;
        }

        private void releaseObject(object obj)
        {
            try
            {
                
System.Runtime.InteropServices.Marshal.ReleaseComObject(obj);
                obj = null;
            }
            catch (Exception ex)
            {
                obj = null;
                MessageBox.Show("Unable to release the Object " + 
ex.ToString());
            }
            finally
            {
                GC.Collect();
            }
        }
    }
}
```

Appendix C

CURRICULUM VITAE

Name Surname: Hazal Ceylan

Place and Date of Birth: Kadıköy 01.01.1990

E-Mail: ceylanha@itu.edu.tr

EDUCATION: Istanbul Technical University

B.Sc.: Geomatics Engineer

PROFESSIONAL EXPERIENCE AND REWARDS:

ALYA PROJECT Map Engineering Consulting Commitment and Trade Limited Company

•City Planning Applications •Land Survey •Digital Cadastre Construction •Construction Reconstruction Plan •Village Overlay Maps •Strip Maps •Expropration Maps •Road Profiles •Land Consolidation Projects •Find Land Survey •GIS/GPS Studies •Hydrographic Surveying •Energy Transmission Study Projects •Excavation - Reserve - Mining Measurements •Survey and Management Map

INFOTECH The Location Intelligence Company

• InfoNav Navigation Systems • INFOANALYST (Create and analyze service data, Analyze effectiveness of services, Location Selection, Risk analysis, Point of sales analysis, Customer distribution analysis, Targeted advertisements, Service and catchment area determination…) • MAPLINK (MapLink enables integration of company's location depended data with city maps. MapLink is an internet mapping service which is designed specially for people’s needs.) • INFORISK (InfoRisk combines spatial information, analysis software and integration services for a better risk management. InfoRisk is particularly intended for insurance and reassurance companies.)

LSCEOA - Licenced Survey Cadastre Engineers and Offices Association

• Gps Studies • City Planning Applications • Land Survey •Digital Cadastre Construction