Assessment of Location of Pedestrian Outdoor Route Navigation Using Shortest Path Algorithm by developing 3D Map: The case of Debre Birhan University Compound

By

Yifru Habtewold

A Thesis Submitted to the Department of Geomatics Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of

Master of Science in Geoinformatics Engineering

Office of Graduate Studies

Adama Science and Technology University

July 19, 2021

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Co-advisor: Roba Gemechu (Phd)

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Declaration

I hereby declare that this Master Thesis entitled “Assessment of Location of Pedestrian Outdoor Route Navigation Using Shortest Path Algorithm by developing 3D Map: The case of Debre Birhan University Compound” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

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Name of the student Signature Date

Recommendation

we, the advisor(s) of this thesis, hereby certify that we have read the revised version of the thesis entitled “Assessment of Location of Pedestrian Outdoor Route Navigation Using Shortest Path Algorithm by developing 3D Map: The case of Debre Birhan University Compound” prepared under my/our guidance by Yifru Habtewold submitted in partial fulfillment of the requirements for the degree of Mater’s of Science in Geoinformatics Engineering.

Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

___________________________	_________________	________________
Major Advisor	Signature	Date
___________________________	___________________	________________
Co-advisor	Signature	Date

Approval Page of M.Sc. Thesis

we, the advisors of the thesis entitled "Assessment of Location of Pedestrian Outdoor Route Navigation Using Shortest Path Algorithm by developing 3D Map: The case of Debre Birhan University Compound" and developed by Yifru Habtewold, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Major Advisor	Signature	Date
Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Yifru Habtewold have read and evaluated the thesis entitled "Assessment of Location of Pedestrian Outdoor Route Navigation Using Shortest Path Algorithm by developing 3D Map: The case of Debre Birhan University Compound" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geoinformatics Engineering.

Chairperson	Signature	Date
Internal Examiner	Signature	Date
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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

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List of Abbreviation

2D	Two Dimensional
3D	Three Dimensional
ASTU	Adama Science and Technology University
CAD	Computer Aided Design
DBU	Debre Birhan University
DEM	Digital Elevation Model
GCP	Ground Control Points
GIS	Geographic Information System
TIN	Triangular Irregular Network
RCL	Route Center Line
SPA	Shortest Path Algorithm
WGS	World Geodetic System
UTM	Universal Transverse Mercator

Abstract

Navigation is determining one's position, planning of a route from initial position to a destination following the route. Travelling in a new environment is a great challenge of human being to arrive the target destination points. Specially, finding the way inside university campus which have many buildings with a number of connections of routes are being more a challenge to unfamiliar person for the campus environment. Most of these routes are pedestrian based. Therefore,in this thesis pedestrian outdoor route navigation with shortest path were addressed and 3D models of the campus were developed, such as 3D route model, 3D route network model, and 3D building models. The 3D models were developed using ArcGIS desktop 10.7.1 and SuperMap iDesktop 10i and shortest path were determined by using Dijkastra's SPA. To implement this SPA and determine the most best route between the origin and destination of pedestrian, directed and weighted graph were developed. So this thesis is used to avoid confusing of the locations of the required destination point with a shortest pedestrian route within DBU campus for unfamiliar people.

Key words:

3D map, destination, navigation, origin, outdoor, pedestrian, route

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

People walk, run, ride and drive throughout their life for finding the way from place to place. Due to the increasing of knowledge and interest of human being to know their origin and destination of themselves the method of navigation science and technology changes until now but not the end. A researcher [1], defines navigation as determining one's position, planning of a route from initial position to a destination following the route. Some people have great sense of orientation, while others face difficulties to find the correct way to their destinations [2]. Therefore, [3], [4] & [5], [6], [7] & [8], people need spatial knowledge and spatial cognition of navigation for planning, orienting, directions, acquisitions and organizations of the route from one location to another.

Based on some researchers description the continuous demanding of user's current position which represents origin and destinations points through 3D map view [10], [11], [12]& [13] becomes more interesting to use in navigation systems for pedestrian and they recommended to update 3D map navigation system with shortest path [18], [19] [22], [23], [26], [27] & [28].

Navigation has two fundamental tasks: Way finding and locomotion as explained by [1], [8], [14], [15] & [16] in section 2.1 in detail. These tasks are performed interactively until people reach their destinations. Based on the explanations of [17] peoples required to know location information using semantic expressions that are imbued with meanings, such as at home or in a library.

This thesis addressed the main objective of pedestrian outdoor route navigation with shortest path by developing 3D map using ArcGIS and SuperMap iDesktop 10i. It also contained and addressed the specific objective with a corresponding research questions that were derived from the main objective. Such specific objectives are determining pedestrian requirements for navigating unfamiliar campus area, developing 3D map and navigating destination points through shortest path with a case study area of Debre Birhan University (DBU).

The requirements of pedestrian for navigating new campus area, which were addressed in current thesis were extensive range of vision [6], free mobility [21], cognitive map to identify their position in the environment [3] [4], location of the destination and the surrounding buildings, Shortest path with information giving direction along the path and so on (see details in section 2.1.1, 2.1.3 and 3.2).

3D models of the campus area were developed for navigating destination point through 3D environment, because it shows the surrounding environments what looks like and increases the level of confidence of pedestrian to navigate destination points. The 3D models that developed in this thesis includes DEM from contour lines, 3D building, 3D route, and 3D network models using input data of DBU plan CAD data set that gets from DBU project construction office. The CAD data set required georeferencing of coordinate points. These coordinate points are ground control points existing in DBU campus. After georeferencing CAD data, then created file Geodatabase data set with each feature class in ArcMap by digitazing the required points, lines and polygons that needs to develop their 3D view in ArcScene.

To determine the shortest path between the origin and destination points, Dijkstra's SPA was used. For implementing this algorithm directed and weighted graph were developed.

> *Estefania Cassingena Navone (2020) in her lecture class she defined that: Directed graph means that for each pair of adjacent connected nodes, the movement of pedestrian are from one node to another in a specific direction. The weight of an edge can represent distance, time, or anything that models the "connection" between the pair of nodes it connects..*

And also, topological network dataset were created for validating line and points error that was not connected correctly.

Then stop data models were developed which contains origin and destination points of pedestrian. Finally, using these weighted and directed graph and also stops model as input data the shortest path were determined using Dijkstra's SPA in Python 3.9.4.

1.2. Statement of the Problem

As stated by[18], [19] [22], [23], [26], [27] & [28] travelling in a new environment is always a great challenge of human being. These previous research were not prepared 3D virtual map view with 3D shortest path navigation but 2D and 2.5D. And also they recommended to update 3D map navigation system. Specially, finding the way inside university campus is being more a challenge to unfamiliar people for the environment. Relative to 2D map view of campus environment, 3D virtual map view is clearer for any map readers. Navigating around a university environment can be difficult for visitors and newcomers, and one of the main reason is because the university environment has the combination of indoor and outdoor navigation [13]. In our country Ethiopia, almost all campuses have text oriented dashboard that tells numbers and name of buildings.

Due to this reason developing 3D map of campus areas with assessment of location of pedestrian outdoor route navigation is very necessary. Debre Birhan University (DBU) campus environment is selected as a case study area which has three entrances and several buildings connecting with a number of outdoor pedestrian routes. Because it has no location of pedestrian route map and building information in each entrance of DBU except only text oriented dashboard with selected building information, such as; president office, registrar, schools and human resource management after walking some distance from the main gate. In addition to this, lack of local cues increases the level of difficulties of finding target destination point in DBU campus. So, this thesis are produced location of pedestrian outdoor route on 3D virtual map view of DBU.

1.3. General and Specific objectives

The general objective of this study is assessment of optimum location of pedestrian outdoor route navigation using shortest path algorithm by developing 3D map of DBU campus starting from campus entrance to the target destination buildings.

The specific objectives of this thesis are to:

1. determine the basic requirements for navigating unfamiliar campus area
2. develop 3D map of features in DBU using ArcGIS
3. determine the shortest route of the destination points using shortest path algorithm,

1.4. Research Questions

To achieve the goals of this thesis the following research questions must be answered:

1. What are the basic requirements for navigating unfamiliar campus area?
2. How to develop 3D location map of campus buildings and routes?
3. Which route is the shortest to arrive the target destination buildings?

1.5. Significance of the Study

Relative to 2D map view 3D map view gives more clear information about the surrounding environments and the true shape of the buildings. Therefore, this study is used to avoid confusing of the locations of the required building information with a shortest pedestrian route within DBU campus for unfamiliar guests, customers, lectures, researchers, international seminar and academic conference participants for the first time and new students who joins DBU with keeping of time lost. In addition to DBU campus it is important to industries and hospitals which have many buildings and pedestrian routes with a number of connections to navigate any target point or building turn by turn by displaying initial and destination positions of pedestrian in new environment.

1.6. Scope of the Study

The scope of this study is to consider the existing building and outdoor pedestrian route to navigate the locations of each building with shortest route through 3D map visualization in DBU campus. It also limited to consider only normal vision persons and unfamiliar for the campus environment.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Pedestrian Navigation

Pedestrians often navigate in unfamiliar environments and sometimes it can be a difficult and challenging task for them to reach their destination [24], [26], [27] & [28]. We can plan a new travel via the Internet, e.g. a long journey across several cities or a short trip for shopping in the same city [22]. According to [14] & [15] cited in [8] who defines navigation as "coordinated and goal directed movement through the environment by organisms or intelligent machines." He divides navigation into two parts: locomotion and way finding. Locomotion is described as "the movement of one's body around an environment." It requires the continuous perception and interpreting of the local surrounds. Whereas, way finding is defined as the goal directed and planned movement of one's body to arrive the target destinations point.

A navigation support must be able to provide location, orientation and movement of the user as well as related geographic information with the real world situation experienced by pedestrians [30]. According to the researchers [31], [32] & [33], University campuses have thousands of new students, staff and visitors who are unfamiliar with the environment, an effective pedestrian navigation system is essential to guide them [13] & [28] in the direction of movement.

2.1.1. Spatial Knowledge and Cognition of Navigation

Spatial knowledge and spatial cognition plays an important role in planning a route between two or more locations. As stated by [3] & [4] human spatial cognition refers to the acquisition, organization, utilization, and revision of knowledge about the spatial environments. As the explanations of several researchers in the field of spatial cognition [5] & [35] cited in [6] and [7] cited in [8], navigating a new environment humans develop the spatial knowledge of landmark (knowledge of reference points or fixed locations), route (information about directions of movement and the geometry of route that connects landmarks) and survey (metric spatial relationships between sets of environmental routes and landmarks). According to [34] & [36] cited in [37] for an effective navigation, people must acquire a set of skills such as perceiving the representations of the environment in which they travel, positioning and orientation during travel and planning of routes by taking several constraints into consideration such as shortest distance, minimum travel time and maximum safety.

2.1.2. Pedestrian Navigation Systems in Campus

Nowadays, according to [24] most of universities have published “campus plans” and “campus maps” on their website, and most of these maps are static representations of building plans. The campus map should be an interactive, online tool that facilitates spatial information acquisition in a manner familiar to the students and staff members brought up in a digital environment.

According to [16] identify two types of interactive online campus maps such as way finding and atlas based model. In the way finding based model the focus is in searching for and locating specific university features (departments, buildings, etc.), and navigating the campus efficiently to reach them. In the atlas-based model, the focus is upon providing numerous geographic discourses about an important place on campus. When designing navigation aids for different people, their orientation capabilities [38], familiarity with the interface [39] and timing of navigation instructions influences the user performance in a navigation context [40].

2.1.3. Characteristics of Pedestrian Navigation System

Pedestrian outdoor route navigation is mainly characterized by in three ways. The first is Restriction of distance which means walking is not a practical mode of transportation when destinations are too far away from origins [20]. secondly, pedestrians can turn their head around freely as they walk to see the environment in any directions [6]. Thirdly, pedestrians are not restricted to following specific paths when walking and may take shortcuts, unlike drivers, who have to drive only on roads and follow road directions [21] & [6] most of the pedestrian navigation systems have a visual interface where the user is provided with a map interface and some extra textual information to assist them in navigation.

2.2. Planning Shortest Path Algorithm

Path planning can by defined as: starting from the Geometric Network Model's graph of the building, with oriented and weighted edges, compute the path from starting to end node in such a way to maximize the usability and success rate while minimizing the chance of the user getting lost[69]. A smarter path planning technique needs to consider users' requirements and customize the path accordingly[9]&[62]. Shortest path is desirable for majority of users and most of the current navigation systems use the shortest path algorithms [66].

Most automated navigation systems rely on computing the solution to the shortest path problem, and not the problem of finding the "simplest" path. When need to compare more than one path[62] &[68], the key points are: compute different shortest paths comparable using different metrics; identify a weighting function that reflect the amount or complexity of information required giving direction along the path, used as a decisional metric for the "simplest" path. [65] proposed weights in terms in its operation and its results indicate that simplest paths are still comparable in length to shortest paths. Another interesting research was made by [67], using the factor of lowest probability of a user getting lost.

In order to produce route instructions, several processes have to be completed [63]. In a first step, the origin and target location have to be determined. In a second step, the system has to compute a suitable route between the origin and target location [64].

2.3. Land Mark Navigation

According to the researchers [41], [42], [43] & [8] landmarks is an object or structure that marks a locality and is used as a point of reference. Based on the explanations of [32] the landmark based positioning is classified into two categories. These are natural landmark based positioning and artificial landmark based positioning

The researchers [41], states that the natural landmark based positioning involves objects in the environment that have a function other than navigation (importantly positioning). The other approach is to use artificial landmarks with easily identifiable shapes specially a triangular shaped marker, patterns or colour [44]. The key advantages of the landmark based positioning in perspective of the pedestrians are firstly, it makes the pedestrian sure that they are on the correct route, since they can see the very landmark which may be a part of their navigational instruction. Secondly, it provides an attractive means of self-orientation. Particularly at decision points, landmarks play a vital role in orienting the pedestrian to the right direction.

2.4. Visual Analysis of Navigation

Based on the facility of graphics (maps) to represents information with the means of geometry, relations and structures, Visual analysis is directly perceivable [46]. The visual analysis is more effective with combination of several views to the data components in a unified display space. According to [47] explanation and cited in [48] the human visual system is effective at recognizing patterns, visualization of data is considered a powerful method in knowledge extraction process. The classification of outdoor route planning based on typical graph based methods are [49] firstly, Shortest-distance, which minimizes the required distance between the start point and destination. Secondly, least-effort, which minimizes the total required time to reach the destination. Thirdly, central point strategy, which finds a route by trying to transit well-known locations (e.g. landmarks) of buildings. Lastly, direction strategy heads to the horizontal position of a destination as directly as possible and regardless of the level changes.

2.5. Location Based Service

Different researchers were defined location based service (LBS) in different way, such as; [29] & [50] defined as LBS is "any service or application that extends spatial information processing, or GIS capabilities, to end users via the Internet and/or wireless network" and [51] & [52] were defined as LBS is "geographically-oriented data and information services to users across mobile telecommunication networks". According to [53] these definitions, both online map services and the Internet GIS can be considered important LBS applications, as they provide the kind of geographic information services via the Internet or mobile-networked environments to mobile devices.

According to the description by [57], location based service, location aware service, location related service and generally location service are interchangeable terms. As stated by [24] that triangulation technique uses the location of at least three known points to determine the users' position. As the explanations of [25] navigation and orientation systems are the most significant part of a modern transportation systems that influences the interaction of a person or an object in a given environment.

2.6. 3D Virtual Map View

Navigation itself largely relies on route division based on successive landmarks along a route, again involving the comparison between and the use of different spatial references [55] & [70]. The use of one of the two current standard mobile map presentation methods, 2D or 3D, considerably influences the navigation performance and spatial reference understanding strategies of mobile map users. 2D mobile maps share the same principles with that of paper maps with which most of the people are familiar, while 3D maps offer additional advantages on understanding reality and its entities [53].

Through 3D maps it is possible to visualize the volume of spatial entities and provide directional multi-views on geo-data and pictorial, detailed representations. These allow for straightforward object recognition, and allow for bigger movement freedom in contrast to 2D maps. In general, 3D maps should follow an egocentric reference frame where the view of reality should be in alignment with the mobile map view point [55]. Although 3D mobile maps show a good potential, experimental user research findings suggest that 2D maps, especially when well designed, are still preferable to 3D maps [71], [72] & [74]. With the use of 2D maps, the mobile map users guided to find and make use of well-known and all round available cues such as road patterns and street name signs. In that case they take advantage of their cognitive maps and body movement, lowering their cognitive efforts required to orient themselves and navigate. The same does not apply to 3D maps, as there is no consistency on the street level perspective and the use of 3D photorealism is problematic on small displays. Still, when orientation and navigation strategies similar to the ones used for 2D maps are applied with 3D maps, the user's performance can be improved [55] & [74].

Many times a bird's-eye view is used to give the illusion of a 3D map to a 2D map, applying a geometric transformation that makes the 2D map shown in a tilted angle. Common in 3D maps, especially in geo-mobile applications made for both pedestrian and car navigation. The use of bird's-eye views does not provide significant advantages over 2D maps in the context of pedestrian mobile users who many times prefer street-view perspectives rather than distant ones [54].

2.7. Conceptual Framework of This Thesis

Pedestrians are free in movement. They can travel in any directions and turn back at anywhere they want. They observe and understand the surrounding new environment and draw a mental map to memorize at the end of travel, especially they leave it. Unlike drivers, traffic rule cannot limit them. Specially in campus area where most of the movement are walking by foot even if from the entrance of the campus to students dormitory, lecture room, academic conference and seminar hall, libraries, registrars and etc. since pedestrians have the origin for their traveling, they also have a goal oriented destination points. If they are unfamiliar for the campus environment, they must need a guidance to make easy the navigation of destination point. In our country Ethiopia, almost all campuses have text oriented dashboard that tells numbers and name of buildings. But it is not enough for navigation purpose. Therefore assessment of location of pedestrian outdoor route navigation on 3D map is necessarily important for every users with saving time by short traveling distance.

In general, this thesis is focused on location of pedestrian outdoor route navigation through 3D map view with shortest path. Therefor, shortest path algorithm is very important to choice the shortest route from the current pedestrian position to the target destination points.

CHAPTER THREE

3. MATERIALS AND METHODOLOGY

3.1. Study Area Descriptions

Debre Birhan University campus (which started learning and teaching process since 1999 E.C) is selected as a study area. Because in campus area most of the routes are pedestrian based and there is more freedom for walking any directions compared to the outside urban area. In university campus area movement of vehicles are limited within a few routes. Most of the movements are pedestrian based.

Debre Berhan University is found south edge of Debre Berhane city, Shoa, central Ethiopia 126 kilometers north east of Addis Ababa on the paved highway to Dessie. Debre Birhan is located between a latitude of 9°36′ N to 9°42′ N and a longitude of 39°30′ E to 39°35′ E with an elevation of 2,840 meters above mean sea level. DBU is located between 9°38' 30" to 9°40' 0" N & 39° 29' 30" to 39° 33' 0"E). The average annual temperature of the city during day and night hour is 17.8°C and 8.83° C respectively with precipitation of 66.17millimeter. DBU is bordered with Tebasi preparatory school and Seat Gebriel church from north, Bersia River from north east, residential house of kebele 09 from north west and west, farming land from south & south east and also farming land ,flower farming & Berisa river from east. DBU covers an area of 1.05 square kilometers. Fig. 3.1 shows location of study area on map of Ethiopia with a scale of 1: 15 000 000 (A), Debre Birhan town at a scale of 1: 150 000 (B) and its map or Debre Birhan University at a scale of 1:30 000 (C).

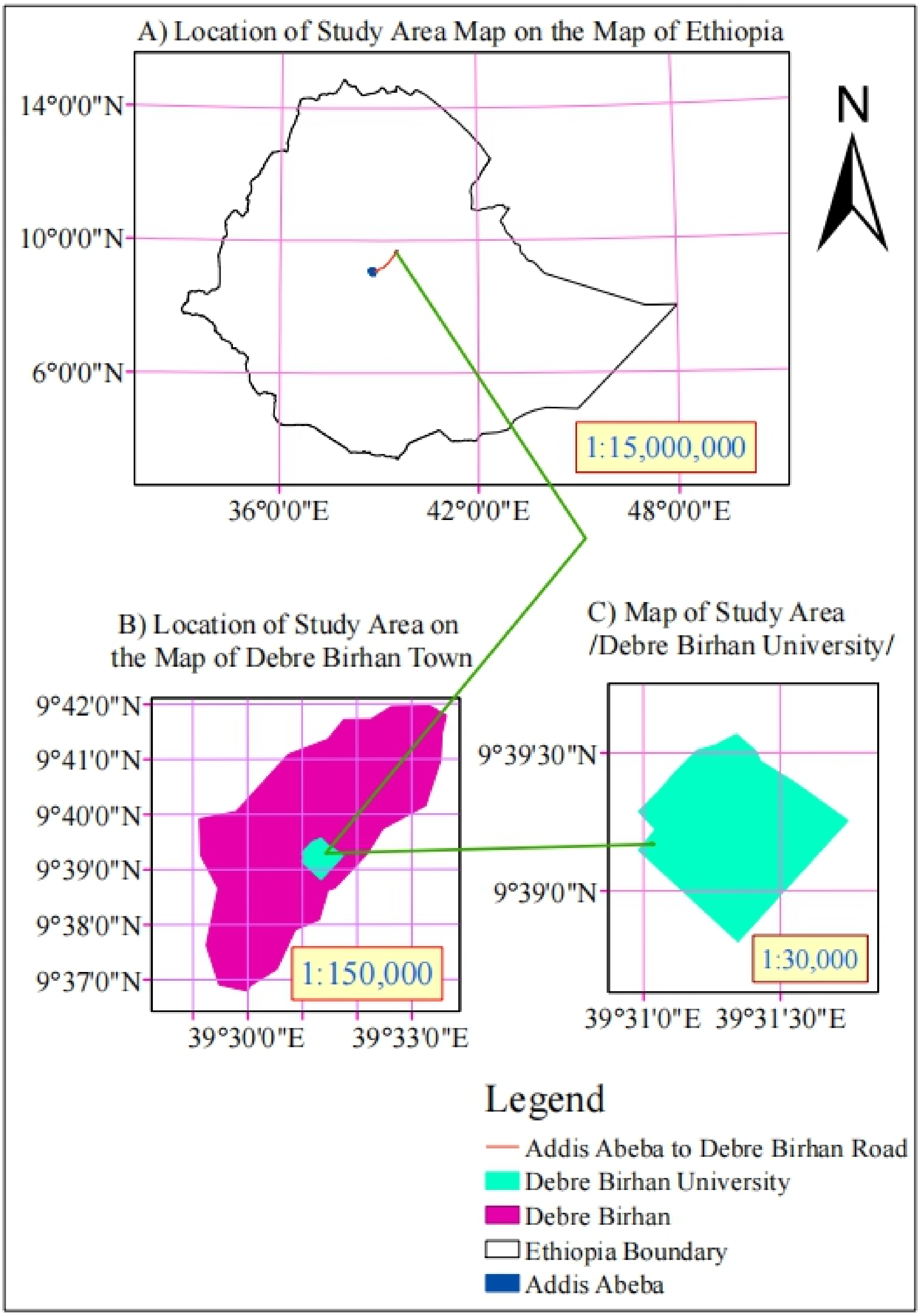

Fig. 3.1. Location of Study Area Map

3.2. Requirements of Navigating Unfamiliar Campus Area

Thousands of students joined and hundreds of participants of symposium and research conference visits DBU in each year. Therefore, a standard outdoor pedestrian route navigation system are required. Almost all of these unfamiliar persons for the campus asked “where…?” and “which…?” questions with regard to their target of destination building? For instance, where is/ are the registrar, library, dinning hall, lecture class, venue of symposium and research conference? In addition to these questions they also ask “which block?” by expecting block number.

So that, the persons who are unfamiliar for campus area, the requirements to arrive the destination building are:

- ✓ Extensive range of vision [6],
- ✓ Free mobility [6], [21],
- ✓ ask questions the persons to know and have a position in the new environment
- ✓ the cognitive map to identify their position in the environment [3] [4], & [34] for detail information (see section 2.1.1),
- ✓ location of the destination and the surrounding buildings[49]
- ✓ Selection of landmarks for an individual route [56]
- ✓ origin of start, Shortest path and information giving direction along the path and so on.

3.3. Data Sources

To complete this thesis work, outdoor data collections and modifications of DBU’s campus environment is required. These data includes DBU’s campus route (route geometry and route attribute), buildings, trees and street light pole features data. Route data covers both pedestrian routes and vehicle route in campus environment. Buildings data includes all buildings with its information (dormitories, post office, graduation & conference hall, cafeteria, campus’s supermarket, laboratories, libraries, clinics, registrars, banks, president office, colleges, lecture buildings). And other important features data; such as, entrance of campus, parking area, sport field,existing reference points, directions of true north and so on existing in the campus environment.

Topographic map and plan of DBU campus environments are the main sources of data which gets from construction project office of DBU. Plan data involves all features existing and futures involve in the campus. But in this thesis work considered only existing features. In general the input data type and sources are summarized in table 3.1 below:

S.N	Data type	Data source	Data format	Remark
1	DBU campus building data	DBU construction project office	*.dwg	
2	Pedestrian path or line data (route network)	DBU construction project office	*.dwg	
3	Campus plan and topographic map	DBU construction project office	*.dwg	Small map scale

Table 3.1 Input data type and its source

3.4. Instruments and Software Used

SuperMap idesktop 10i and ArcGIS desktop 10.7.1 are used to prepare 3D map to make more clear view of location of building and in addition to these Python 3.9.4 (64 bit) to generate Dijkstra's shortest path algorithm for navigating campus buildings with shortest route.

3.5. Data Analysis

To develop a Smart Campus Map, it starts from mapping the environment and then link it to the buildings by considering all steps from mapping to navigation [9]. Good navigation system not only guide users to a destination, but also support them in understanding the environments [19], [22], [58] & [59]. So, pedestrian feel confidence to reach their target destination points on their own.

Another study also shows that routing between two locations is performed on the basis of the network lines (which is made up of many line segments and including their buffering areas [60]) using the Dijkstra's shortest path algorithm [8]. Therefore, line buffering is considered as a potential technique to estimate the location of pedestrian paths [60], using DBU campus route network as a reference. As described by [61], the location of the user has to be known, as well as the geo-reference of the data, and both need to be in a compatible format.

In general, to complete this thesis from the beginning of data collection stage to the final output the following stages are required:

1. Data collections
2. Check accuracy of data
3. Data prepare
4. Data processing
5. Planning Shortest Path Algorithm [73], [74]& [75]

3.5.1. Data collections

To develop 3D map of study area (DBU compound) and outdoor route navigation with shortest path, it starts from collecting outdoor data. These data are getting from DBU project office in auto CAD or (.dwg) data format (see table 3.1 under section 3.3). It needs to convert shape file (.shp) data format using ArcGIS desktop or SuperMap idesktop 10i.

3.5.2. Check accuracy of data

The data used in this thesis is the adjusted data getting from DBU construction project office. The required positional accuracy of data are adjusted using route mean square error after data collections and checked by DBU project office. Even if, the data is adjusted, it requires Geo-referencing data which referenced with either of study area boundary or DBU building. Due to this reason the data is used directly to develop 3D models of DBU.

3.5.3. Data prepare

The data must be prepared to the compatible format for 3D ArcGIS desktop and SuperMap idesktop 10i. The data getting from project office of DBU is in auto CAD drawing (.dwg) format which need to convert the data to shape files(.shp) format. Because shape file (.shp) data format are needs to create File Geodatabase (.gdb), Personal GeoDatabase (.mdb) data format and digital elevation model image (.jpg, .tif) file format or (ShapeFile to TIN to DEM) which is compatible for ArcScene and Scenes in SuperMap idesktop 10i to prepare 3D map of the study area and features existing in it. To prepare data for data processing, keep in mind the following procedures:

1. Geo referencing CAD data with ground control point (GCP) existing DBU.
2. Auto CAD (.dwg) data format needs to create Spatial Reference before converting or exporting to ShapeFile (.shp) data format,
3. Next, define projection, in projected coordinate system WGS 1984_UTM_ Zone_37N.

4. Next, using 'selection by attribute' method, select the required data, (such as; routes, buildings and contour lines) and export to shape files or digitizing and store in geo database dataset format which is suitable for ArcScene to develop 3D models.

3.5.4. Data processing

Under data processing stages the following components are determined and identified:

1. Scale of map
2. Landmarks
3. features existing in DBU campus

1. Scale of map: is determined based on the required accuracy of visibility of features. In this thesis, the scale of map is vary from map to map but they are not smaller than 1:10 000.
2. Landmarks: Distant landmarks such as towers or mountain peaks are visible from a large area and can serve as global landmarks; but local landmarks are visible only from a small distance[32]&[42]. Local landmarks can be used either for guidance, as reference points guiding the observer to the intermediate goal[43], or as pointers, directing the observer's way onwards from the intermediate goal[45]. Landmark function is not a unique property of a particular object but depends on how the navigator uses that object[70]. In fact, one object serving as a global landmark in some phase of the navigation task may serve as a local landmark later
3. Features existing in DBU campus: In this thesis, features identifying that exists in DBU are buildings (dormitories, administrating block, Clinic, laboratories, Cafeteria, Registrar, Libraries, Graduate hall, College of Postgraduate, and College of undergraduate), routes such as vehicle and pedestrian ,parking area, trees, street lights and sport fields.

3.6. Developing 3D Model

Existing features in DBU that requires to develop 3D Model and route network analysis are stored in geodatabase using ArcCatalog. These geodatabase include; polygon dataset (buildings, sport fields and green area),point dataset (trees, cars, and street light poles) and route geometry (pedestrian and vehicle route). After creating of these geodatabase, designing 3D model was started for polygon and line (route) geodatabase by exporting and digitazing CAD dataset (for details, see section 3.5.1 to 3.5.3). Point geodatabase also is designing around route and building (trees, pole) and on the route (car) dataset. Fig 3.2

shows the general work flow of developing 3D models. But to develop 3D models of each feature class,there were its own work flow.

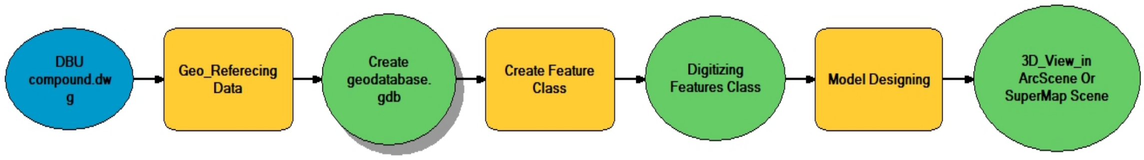

Fig 3.2. work flow of Developing 3D model

3.6.1. Generating 3D map view of the study area

Firstly, prepared contour map of the study area, then using these contour lines prepared TIN and convert TIN into raster or digital elevation model (DEM). Next produced 3D map of DBU in ArcScene. The contour map of DBU is shown in fig 3.3. The vertical distance of this contour map is 1 metre.

Then create TIN data of study area (DBU compound from these contour lines using 3D Analyst Tools of ArcGIS (see fig 3.4). In another ways, TIN model of study area is created using Model Builder tools. The input and output data is DBU contour lines and DBU TIN Model respectively with the coordinate system of WGS_1984_UTM_zone_37N(See fig 3.5). Using TIN image of DBU as input data, DEM is prepared.

The aim of producing the study area of DEM is to generate 3D map of it. Because 3D map is more clearly shows the surrounding environment of the area. Using model builder tool, DEM is also generated. DBU TIN Model is used as input data and ‘TIN to Raster’ is a tool to get DEM model as output, see fig 3.6. Both TIN and DEM are stored in raster dataset using ArcCatalog.

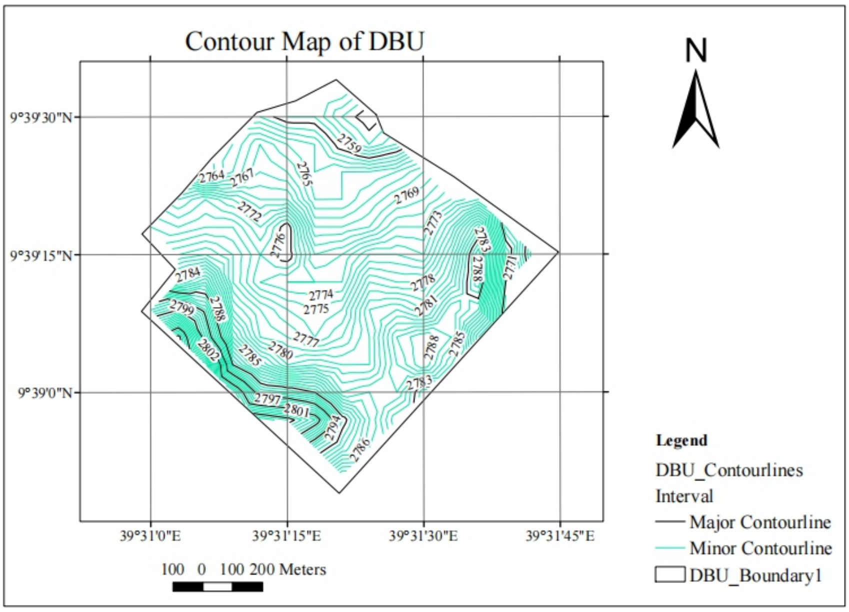

Fig 3.3. Contour map of DBU

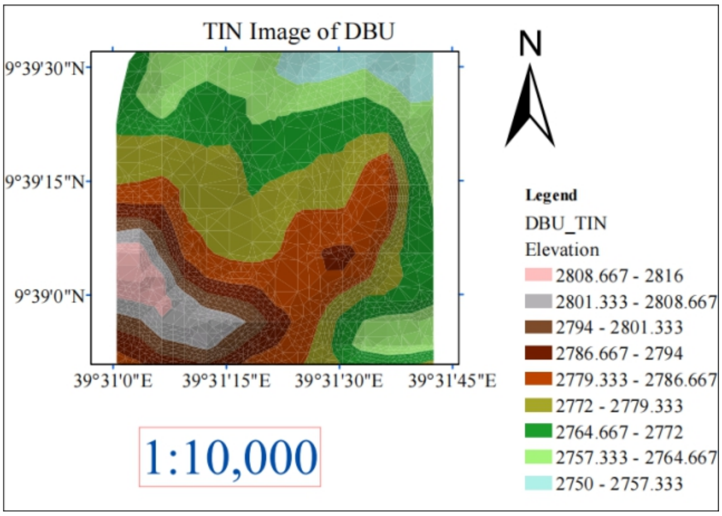

Fig 3.4. TIN image of DBU compound

Fig 3.5. TIN model of DBU compound

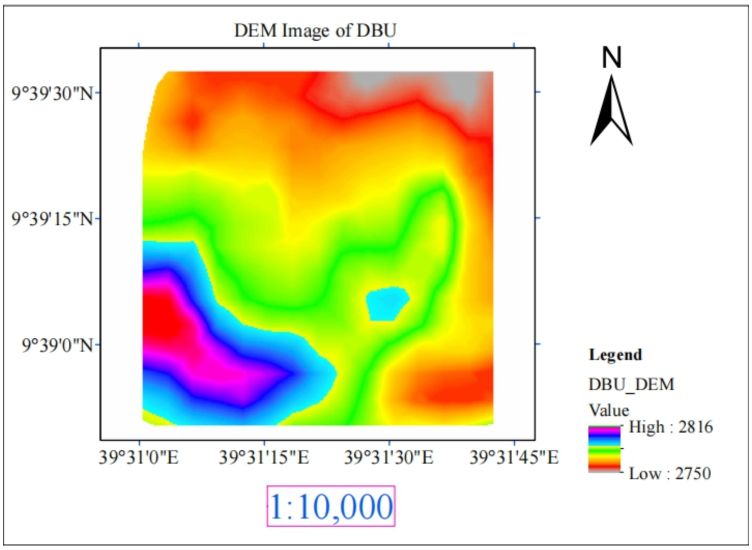

Fig 3.6. DEM Image of DBU

Fig 3.7. DEM model of DBU

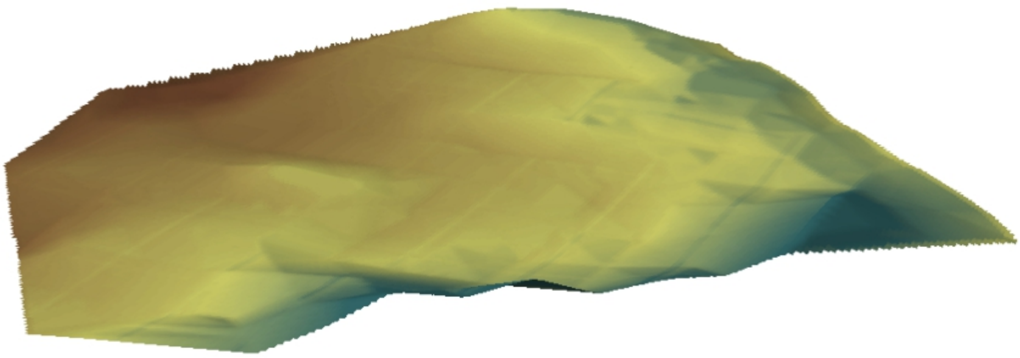

Fig 3.8. 3D view of study area

3.6.2. Developing 3D Point Model

Trees, street light poles and cars are symbolized by points in a 2D surface. Such features 3D models are developed by point digitizing system and stored in geodatabase (.gdb) file format.

3.6.3. Developing 3D Building Model

After exporting building shape file (.shp) format into File Geodatabase (.gdb) format with building attribute which contains building information 3D building model is built. In this 3D building model, only considered building structures, roof structure is not considered. The procedure of developing 3D building model is starting from making georeferenced with GCP existing in DBU and spatial reference of CAD data (.dwg) file. The second procedure is creating polygon feature dataset in File Geodatabase (.gdb) format. This is done into two ways. (a) building feature class is created by digitizing CAD (.dwg) file. (b) By exporting CAD file into ShapeFile (.shp) feature dataset and then convert it into polygon feature dataset because the input CAD dataset is polyline dataset. Therefore, it requires converting into polygon dataset. The footprint of the building structures, procedures and developed 3D building model with supported file format for Arcscene on 3D surface of study area is shown in fig 3.9, fig 3.10 and fig 3.11 respectively. Adding vertical distance value,i.e. building elevation on 2D layer is considered as 3D models of building.

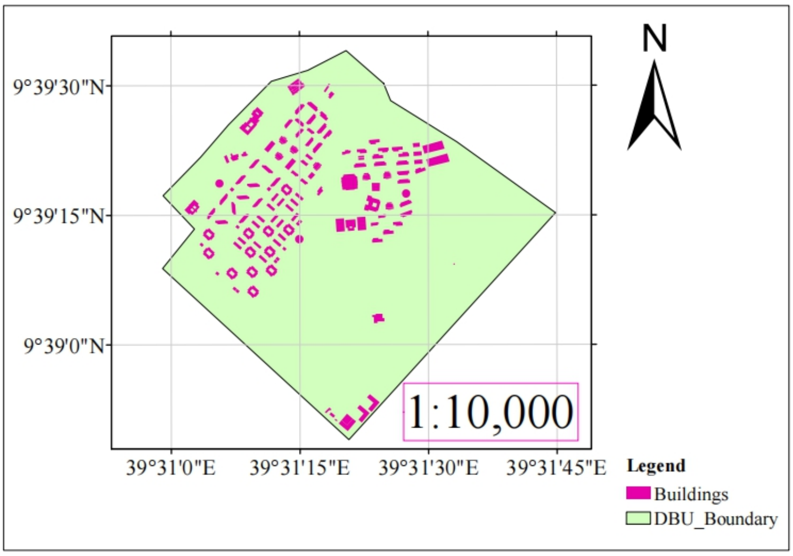

Fig 3.9. DBU building footprint on 2D surface in*.gdb file format

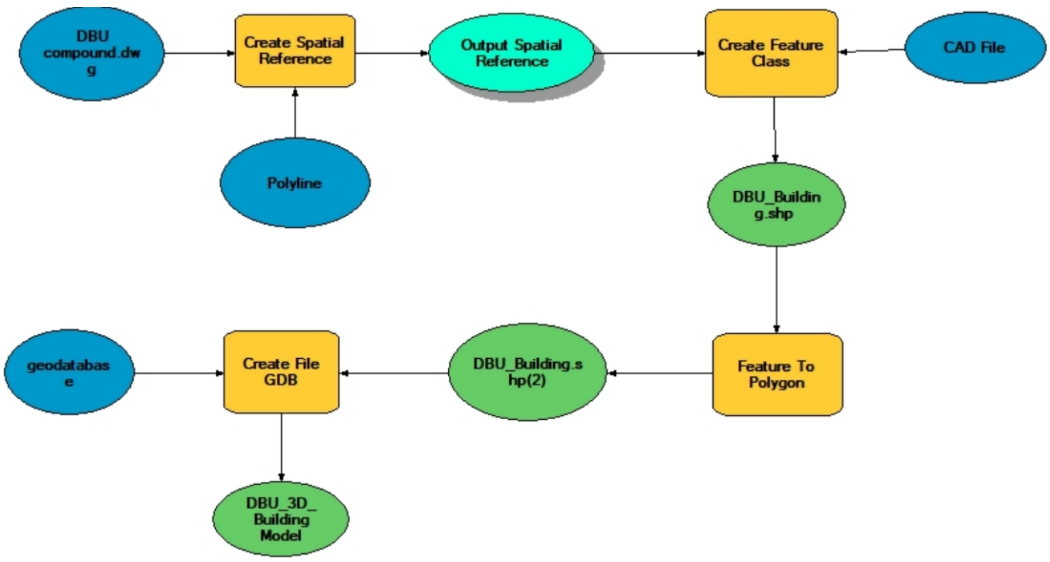

Fig 3.10. work flow of 3D building model

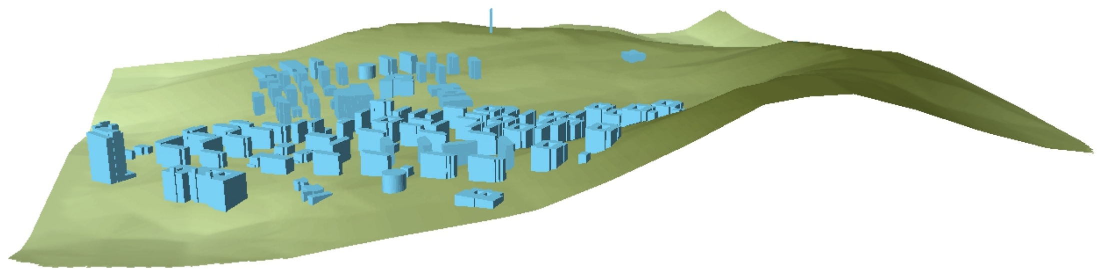

Fig 3.11. 3D model of DBU building on 3D surface in ArcScene desktop 10.7.1

3.6.4. Developing 3D Pedestrian Outdoor Route Model

CAD data(.dwg) file format is requires geo referencing with the known control point or GCP existing in DBU compound and create spatial reference for getting Referenced CAD data (.dwg) in WGS 1984 UTM Zone 37N coordinate system. The referenced CAD data can be used to create file Geodatabase (.gdb) file format in two ways.

1. By exporting CAD dataset: CAD dataset also export to geodatabase into two ways.

   a. Referenced CAD data format directly export into File geodatabase feature class.

   b. Referenced CAD data export into ShapeFile (.shp) data format and then created features dataset, next, export into File geodatabase (.gdb) feature class.

2. By digitazing CAD data set: first for, feature data set as line data set and feature class as route is created under file geodatabase. Then, digitize CAD data set and stored into geodatabase (.gdb) file format.

During this time, 3D route geometry model was created with route attribute.The attribute contains; route purpose, buffer width and travel distance between each vertices. Fig 3.12 and fig 3.13 shows DBU 3D route model designing procedures and the generated route respectively.Then Network data set is created using route model data as input data.This

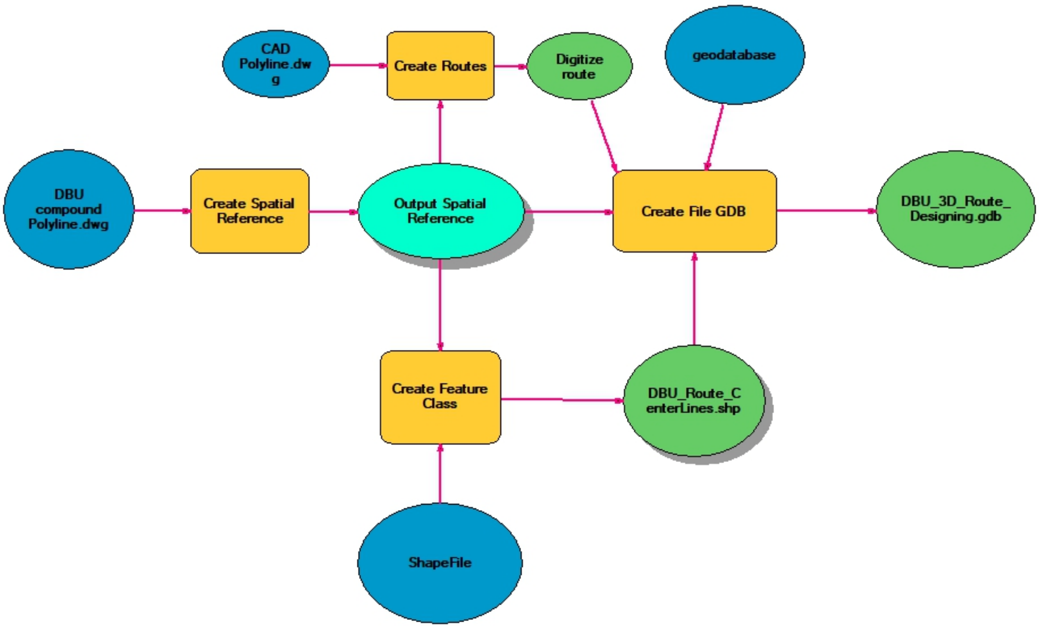

Fig 3.12. work flow of 3D Route Model

Stage is the beginning of development of 3D outdoor pedestrian route network analysis.

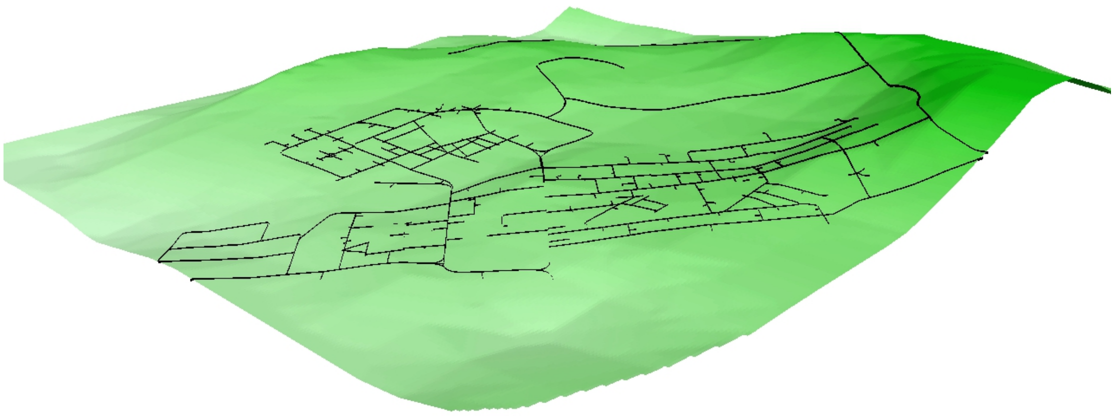

Fig 3.13. Generated Route model on 3D surface of study area

3D outdoor navigation is developed to navigate locations from origin to destination and at the same time to understand the real shapes of buildings, and other objects. As stated by [71] in 3D navigation system, users can see how the real environment looks like. For more details see fig 3.14.

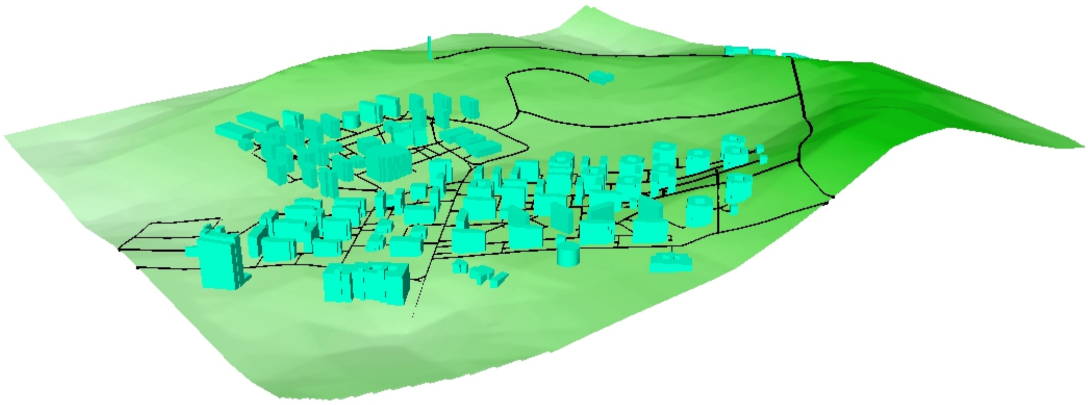

Fig 3.14. 3D Route model with 3D building in DBU

3.6.5. Developing 3D Route Network Model

The need of route network analysis in this thesis is used to determine the shortest path from origin to destination points based on existing paths using Dijkstra's shortest path algorithm(SPA). To navigate location of the route, the navigators must be select their origin and destination points and the algorithm can be determine the shortest path from the network. SPA is implemented and generated in Python 3.9.4 (64 bit). Fig 3.15 shows the stage of creating route network data set with node of each edge. The node must connect to each other with adjacent route edge.

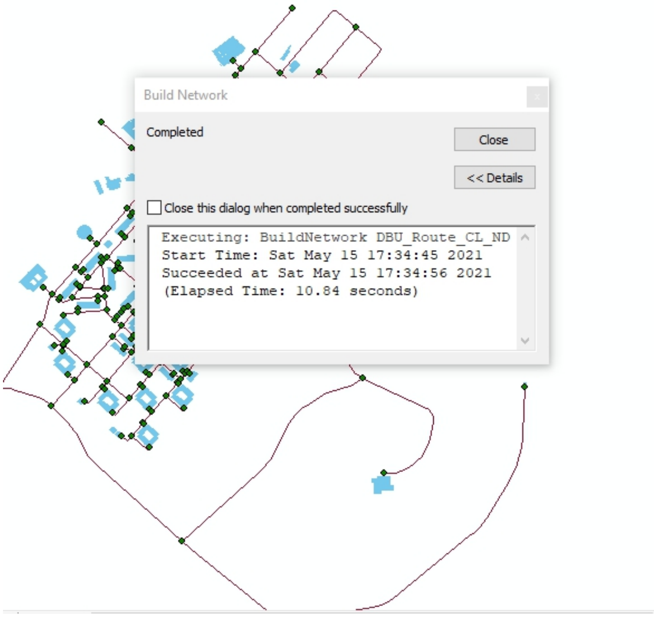

Fig 3.15. Complete Build Network dataset using ArcMap in *.gdb format

Fig 3.16 shows created network data set which is completed as shown in fig 3.15. The point and line represents route node junctions and edge of routes that connects the node. During processing of network dataset built or after completing the process; the required information were specified in the attribute table. For instance, variables names, data types and so on were specified.

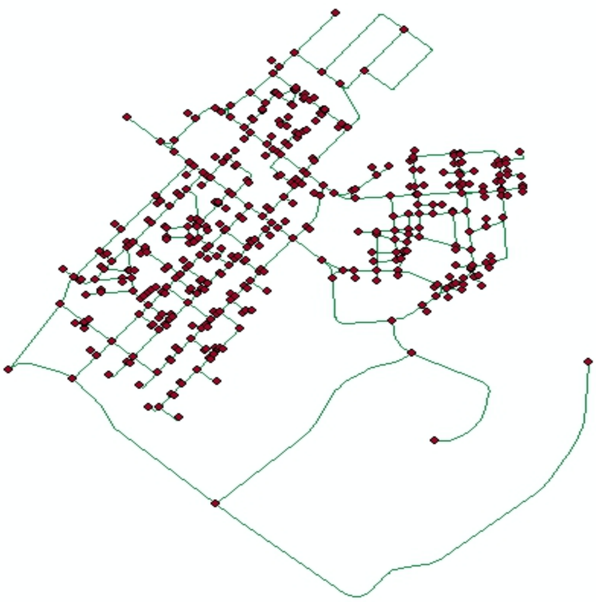

Fig 3.16. Built route network dataset of study area

For this network dataset, create topology, then adjust line and point error and validate it. The next work was 3D route network analysis by taking network dataset as input data.

Using ModelBuilder and Network analysis tools (see fig 3.17); 3D route network analysis were built to generate route layer and solving the route between starting and destination points shown in fig 3.18. As stated by[72] created a 3D connectivity graph from each adjacent nodes.

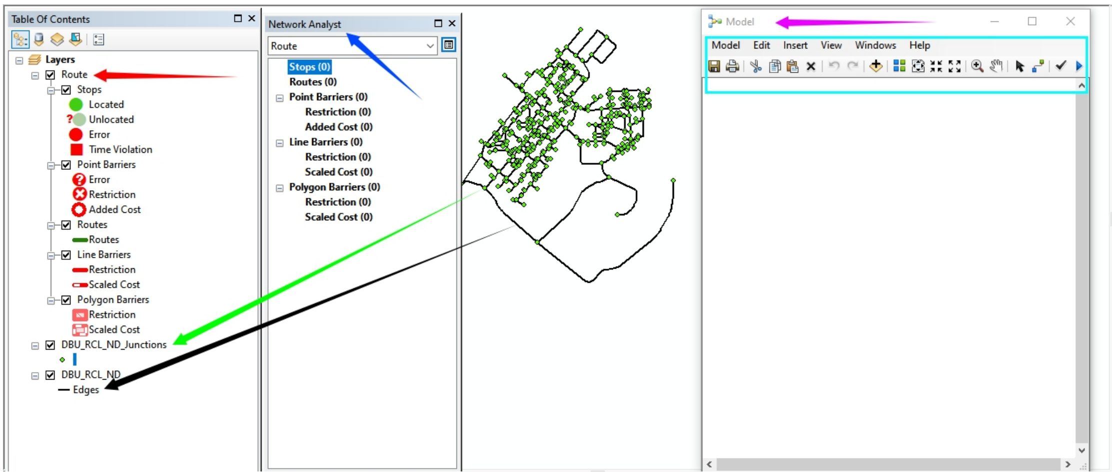

Fig 3.17. shows route layer, ModelBuilder and Network Analysis tools

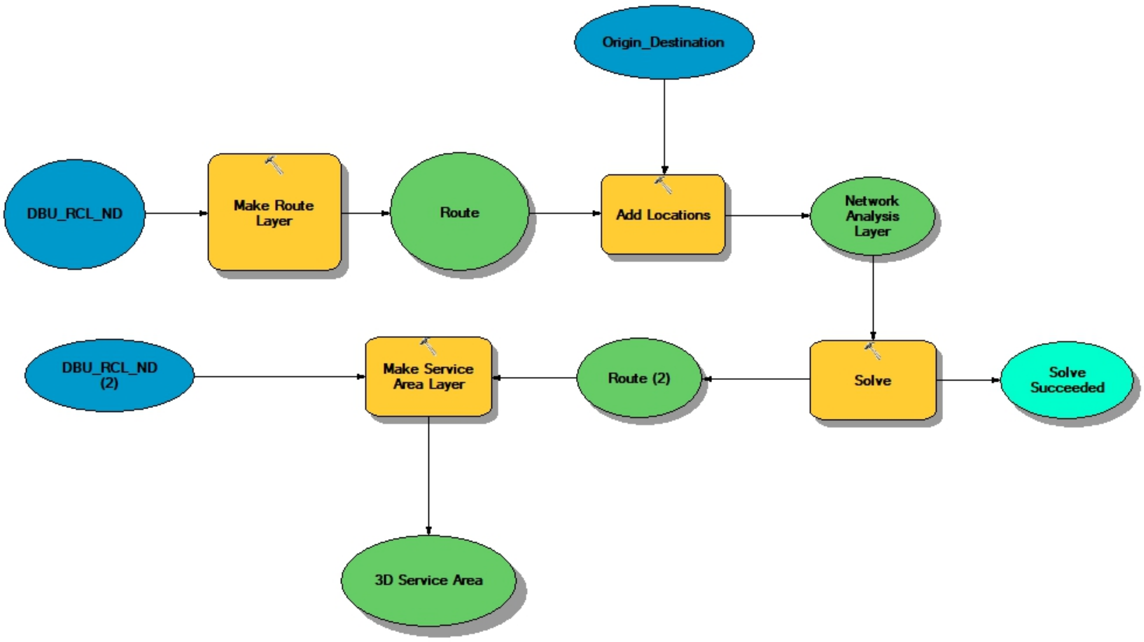

Fig 3.18. 3D Route Network Analysis

After completing 3D Route Network analysis, locations of origin and destination points of target, turning junction node and distance edge between each nodes were stored in one place named by ‘Origin_Destination’. For this thesis work, 17 nodes were selected (see fig 3.19) to find shortest path between two nodes from 433 existing nodes in the build network. The destination points are buildings that the navigators need to arrive.

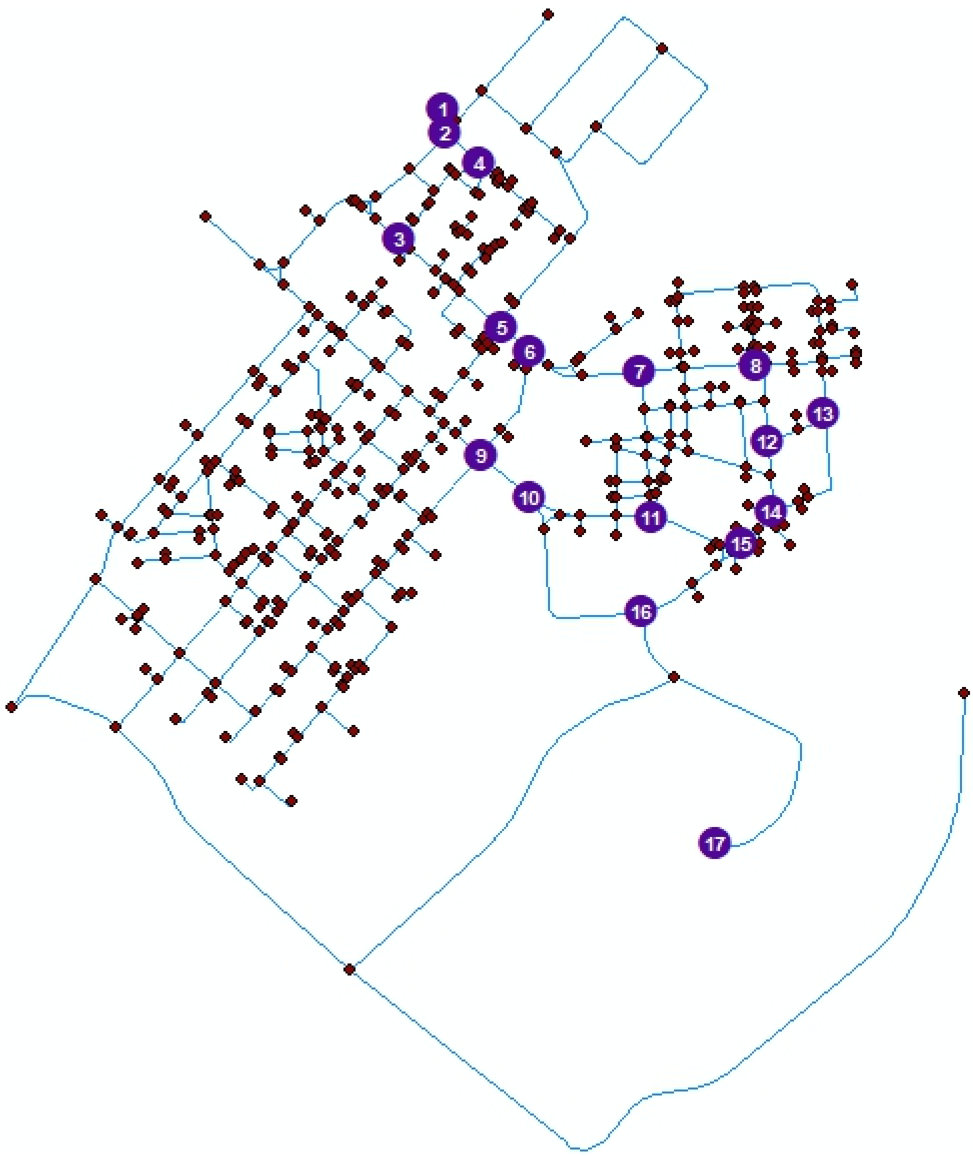

Fig 3.19. Graph of Origin_ Destination with edge of connectivity

3.7. Planning Shortest Path with Dijkstra's SPA

Planning path is the basic requirement for navigation pedestrian outdoor route. Dijkstra's algorithm could be used to solve single-source shortest route problem for a directed graph with non negative edge weights [9]&[40]. In his algorithm the distance is zero at the origin vertex,and all other distance is considered as infinity. All vertices adjacent to the origin is selected as the next origin vertex. The vertex represents building and edge weight represents pedestrian route. The shortest route between origin and destination point or building is determined using Dijkstra's SPA. Following the steps listed below, to generate Dijkstra's SPA in Python 3.9.4 (64 bit).

Step 1: create a graph

Step 2: initialize the origin node

Step 3: assign a variable called path to find the shortest distance between all the nodes

Step4: assign a variable called adj_node to explore it's adjacent nodes.

Step 5: assign a variable called queue to append unvisited nodes and to remove the visited nodes.

Step 6: assign a variable called graph to implement the created graph.

As stated by [48], [62] &[64] when need to compare more than one path, the key points are:

- ✓ compute different shortest paths comparable using different metrics;
- ✓ identify a weighting function that reflect the amount or complexity of information required giving direction along the path, used as a decision metric for the "simplest" path.

Hence, the algorithm for finding the shortest path is calculated by the equation stated by Dijkstra and used in [73]

alternative = graph[cur][i] + path[cur] …………..equation (3.1)

Where,

cur = current arrived node

graph[cur] =shortest path from origin node to current arrived node

path[cur] = shortest path from current arrived node to destination

alternative = the shortest path from the source node to destination via node cur

The system allows users to plan shortest routes between the specified set of buildings. The researcher [27], stated that, users can also drag a marker and place it at any point on the campus from which they want to generate a shortest path. The system dynamically calculates the new shortest path and updates the map display accordingly.

Let see the graph created and connected by adjacent edge which is the existing route of DBU campus. But the graph is un directed and unweighted. This mean that the movement of direction and the edge distance (weight value) was not assigned. Therefore, it needs making of the graph directed and weighted. As shown in fig 3.20, the origin node is node 1 and the destination node is 17. Therefore, to navigate the shortest path from node 1 to node 2 all selected nodes for each edge is assigned and labeled as shown in table 3.2. At initial node the edge distance at it self is assigned to zero and for all others nodes the edge distance is assigned to infinity (∞), because the edge distance were not determined. Hence, before determining the initial node, all of them were unvisited. Let say N denotes for all nodes in the graph G, then the set of unvisited node N has 33 elements, i.e N : {1,2, 3, ….,33}. when determining the initial node from the set N, it is considered visited node and the remaining are unvisited, that means N: {1,2,3,…..,33}. Then determine the edge distance to its adjacent node and update it from initial node with the weight of the edge connected to it. Here the initial node is 1 to represent college of post graduate and its adjacent node is 2 with update weight value of edge distance from infinity to 36.418m. Here node 2 is visited, the remaining nodes are unvisited. Now for node 2 determine the adjacent nodes, such nodes are node 3 and 5 with mark as visited nodes. Then select the closest node from node 1 and add it to the path. The edge distance between node 2 and 3 is 48.481 and from node 2 to 5 is 54.369 m. Therefor, the path from initial node 1 to node 3 is the sum of the distance from node 1 to 2 and 2 to 3. that is 36.418m + 48.481m = 84.961m, and similarly the path from node 1 to 5 is 36.418m + 54.369m = 90.517m, so that the shortest path from the initial node 1 is node 3.

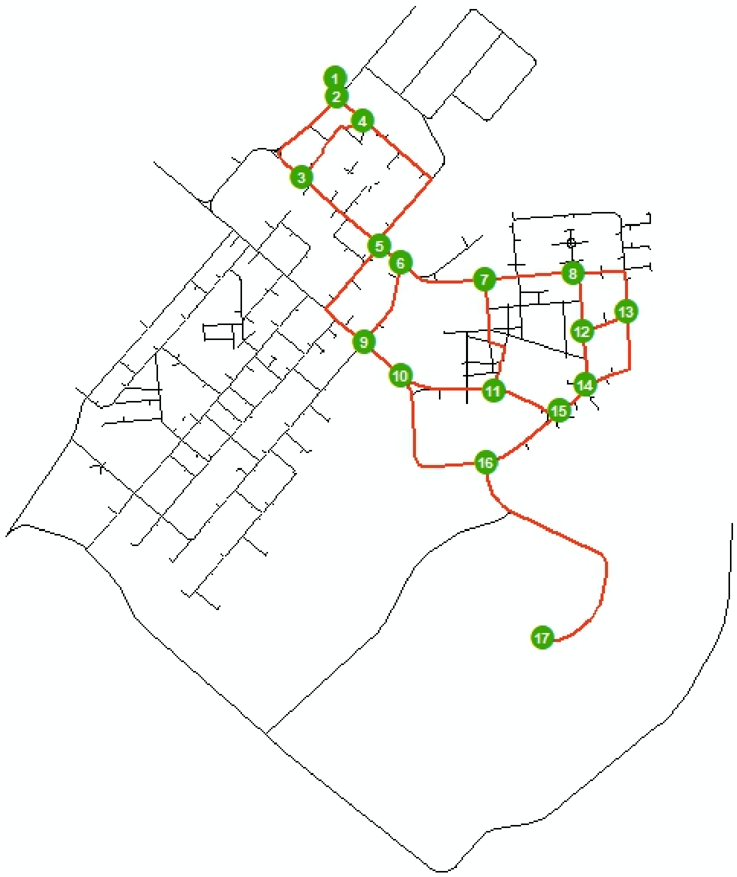

Fig 3.20. Graph of Selected node for generating SPA

Then, node 3 is marked as visited node and the adjacent node for node 3 are node 4 and 11 with edge distance of 63.064m and 123.469m respectively. So the closest adjacent node for node 3 is node 4. Therefore, the shortest path from origin is the sum of weight of previous path and distance of current node, i,e 84.961m + 63.064 m = 148.007m. The next adjacent node for node 4 is node 5 and 8, but node 5 is already visited, so ignore it. Here, node 8 is the only adjacent for node 4 with edge distance value of 66.943m. Therefor, the path from origin node to node 8 is the sum of the value of previous path and the current node. In general the analysis and finding the shortest path is continued in similar way for other unvisited nodes and also calculated using equation (3.1) until reached the destination point.

Let as see Dijkstra's shortest path algorithm implementation using Python 3.9.4 (64 bit) to find the shortest path from college of postgraduate (Node 1) to soil laboratory (Node 17). The node is assigned by N with node number, like N1, N2,….N17.

Node	Edge Distance		Path (origin to current node)	Remark
N1	0	0	0	Origin
N2	36.191	N1 to N2	36.191	Shortest path
N3	159.543	N2 to N3	195.734	
	129.962	N4 to N3	214.903	
N4	48.75	N2 to N4	84.941	
N5	247.618	N4 to N5	332.559	
	144.087	N3 to N5	339.821	
N6	37.515	N5 to N6	370.074	
N7	126.091	N6 to N7	496.165	
N8	123.25	N7 to N8	619.415	
N9	186.74	N5 to N9	519.299	
	125.937	N6 to N9	496.011	
N10	67.573	N9 to N10	563.584	
N11	171.562	N7 to N11	667.727	
	135.791	N10 to N11	699.375	
N12	83.683	N8 to N12	703.098	
	67.6	N13 to N12	814.697	
N13	127.682	N8 to N13	747.097	
N14	74.097	N12 to N14	777.195	
	144.125	N13 to N14	891.222	
N15	103.356	N11 to N15	771.083	
	48.745	N14 to N15	825.94	
N16	227.232	N10 to N16	790.816	
	129.056	N15 to N16	900.139	
N17	394.942	N16 to N17	1,185.758	Destination

Table 3.2 Edge distance between adjacent nodes and path to the current node

The result shows that the shortest path between N1 and N2 is shown in fig 3.21

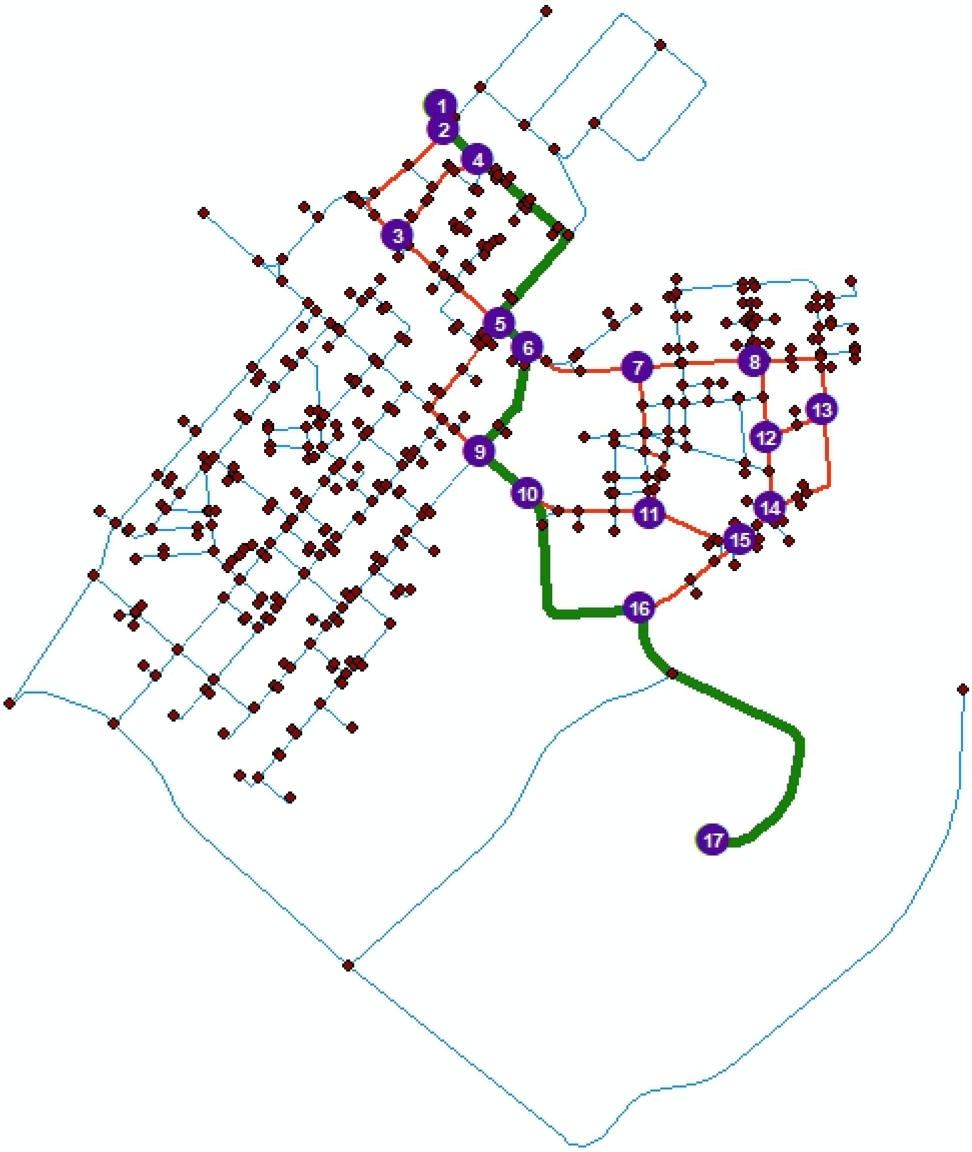

Fig 3.21. Location of shortest path between N1 & N17

CHAPTER FOUR

4. RESULTS AND DISCUSSION

To select campus area for the case study of this thesis is based two reasons.

1. Relative to the outside city environment it is more focused in pedestrian navigation system.
2. It is free for moving and crossing any directions without restriction of traffic rule which is mandatory for outside city.

The main outcomes of this thesis are addressed to answer the research questions with corresponding objectives. Recall here the research questions described in section 1.3 , for making discussion of results.

1. What are the basic requirements for navigating unfamiliar campus area?
2. How to develop 3D location map of campus buildings and routes?
3. Which route is the shortest to arrive the target destination buildings?

Let as see one by one in the following section.

4.1. Basic Requirement for Navigating unfamiliar Campus Area

For a new campus environment, outdoor pedestrian route navigation is a route from a specific location of origin to a specified destination building. To arrived the destination building the persons needed to descriptions of the route. Therefore, the requirements for navigating unfamiliar area are discussed in section 2.3 and also as discussed in section 3.2, landmarks make pedestrian sure that they are on the correct route.

4.2. Development of 3D map of Campus environment

3D models of buildings and route are developed including DEM of the study area. As explained in Table 3.1 the data source used in this thesis were in vector format. The final output also in vector data format Except DEM of the study area which is raster format. Because vector data format is very important for analyzing building and route network. In other words, the vector data represents a collection of three geometric features that developed their 3D models in this thesis work, such as points, lines, and polygons. Under the categorization of these features, there were developed the 3D models of points, buildings, routes and networks.

The 3D models of point features are developed, for such objects (trees, cars and street light) existed mainly in the study area (DBU).

Developing 3D models of building helps the pedestrian to understand what looks like the structures of the destination building. So that this makes easily differentiate and navigate the destination of the pedestrian. Because in ArcScene, the extrusion function is used to connect the geometry of the building on the ground to make the 3D representation.

The shortest path algorithm is working in network data sets. Therefor, 3D route and network models were developed as discussed in section 3.63 and 3.6.4 with topology and graph models of the pedestrian outdoor route. The development of topological models were required to check connectivity errors of the line and points with validating them. The graph models with directed and weighted value or positive value also developed for validating the SPA. All feature classes were assigned by height in order to develop their 3D views.

> *A researcher [60], "explained a pedestrian network is mainly employed in pedestrian-related navigation systems and measuring network connectivity for urban planning. For navigation systems, the correctness of the network and the locations of map features have a great impact on route computation and route guidance. The spatial road network data requirements of car navigation systems can be used as a starting point for determining the data requirements of pedestrian network data since both network data".*

4.3. Navigation with Shortest Path

Finding the shortest path between origin and destination points were the problems of many persons. Therefor, to address the third objectives of this thesis, shortest path algorithm is used. Finding shortest path between two points, which means from origin to the destination is possible using Dijkstra's shortest path algorithm. To implement this algorithm developing network models are necessary. So that the network models were developed as discussed in section 3.6.4 and fig 3.12 shows 3D route network models. The shortest path algorithm were implemented using directed and weighted graph with selection of 17 nodes(see fig 3. 21) from 433 nodes(see fig 3.19) in Python 3.9.4 (64 bit). for these 17 nodes the origin node is 1 and destination is node 17. The result shows that the shortest path between N1 & N17 is N1 _N2_N4_N5_N6_N9_N10_N16_N17.

5. CONCLUSION & RECOMMENDATION

5.1. Conclusion

In this thesis work three tasks were done. The first one is identification of the requirements for navigating outdoor pedestrian route in unfamiliar campus area. Such requirements are discussed in section 3.2, for instance, giving information about the direction of route, shortest path to arrive destination, location of target building and so on.The second task is developing 3D map of the campus area. So that 3D view of DBU compound were developed. These includes development of DEM from contour lines, 3D building models, 3D route models and 3D network models. The final result shows that 3D models are more precise to navigate pedestrian outdoor route in the study area. The last task is navigation of the destination building with shortest path algorithm.This algorithm is implemented by developing directed and weighted graph. The graph contains stops data model (origin and destination of pedestrian), edge of route networks (distance that connects adjacent nodes) and nodes between two edges. These components of graph are essential for finding the shortest path from origin to destination of pedestrian. The shortest path from the selected origin to destination is determined using Dijkstra's shortest path algorithm in python 3.9.4 (64 bit). From the whole existing nodes in the route network of the study area 17 nodes are selected for implementing Dijkstra's SPA starting from node 1 and ending at node 17. The result shows that the shortest path is moving along N1_N2_N4_N5_N6_N9_N10_N

16_N17 as shown in fig 3.21.

5.2. Recommendation for Future Work

This thesis work addressed developing 3D models of building, route and network data sets for outdoor route pedestrian navigation. And also finding shortest path between origin and destination points using Dijkstra's SPA. Therefor, the recommendations of the author for future thesis workers and researchers should extend the current pedestrian outdoor route navigation network data model into 3D web scene with animation in the same or similar study area. Future researchers on pedestrian outdoor route navigation in 3D map can be improving, developing in new methods. In future research work finding the shortest path between origin and destination points will be done by comparing more than one SPA.The future thesis maker or researcher also considers unnormal vision person related to or in similar titles to this thesis.

REFERENCE

[1] Gangaputra, R., (2017). Indoor landmark and indoor wayfinding: The indoor landmark identification issue. Unpublished master's thesis. Technische Universität München.

[2] Marina Georgati, 2019. A 3D Routing Service for the Indoor Environments, A Service for the Aalborg University Campus in Copenhagen.

[3] Denis, M. and Loomis, J.M., 2007. Perspectives on human spatial cognition: memory, navigation, and environmental learning. Psychological Research, 71(3), pp.235-239.

[4] Gaisbauer, C. and Frank, A.U., 2008, May. Wayfinding model for pedestrian navigation. In AGILE 2008 Conference-Taking geo-information science one step further, University of Girona, Spain (Vol. 9).

[5] Werner, S., Krieg-Brückner, B., Mallot, H.A., Schweizer, K. and Freksa, C., 1997. Spatial cognition: The role of landmark, route, and survey knowledge in human and robot navigation. In Informatik'97 Informatik als Innovationsmotor (pp. 41-50). Springer, Berlin, Heidelberg.

[6] Millonig, A., & Schechtner, K., 2007a. Decision Loads and Route Qualities for Pedestrians — Key Requirements for the Design of Pedestrian Navigation Services, chap. 10, (pp. 109–118). Springer Berlin Heidelberg.

[7] Daniel R. Montello, 1998. "A new framework for understanding the acquisition of spatial knowledge in large-scale environments". In: Spatial and temporal reasoning in geographic information systems, pp. 143–154.

[8] Fellner, I., 2015. Auto-generated routing instructions with landmarks for indoor navigation (Doctoral dissertation, Master Thesis at the Paris Lodron-University of Salzburg).

[9] Davidson, P., 2013. Algorithms for Autonomous Personal Navigation Systems. (Tampere University of Technology. Publication; Vol. 1171). Tampere University of Technology

[10] Nikoohemat, S., 2013. Smart Campus Map. Technical University of Munich Faculty of Civil, Geo and Environmental Engineering Department of Cartography.

[11] Pagliari, D., Cazzaniga, N.E. and Pinto, L., 2015. Use of assisted photogrammetry for indoor and outdoor navigation purposes. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(4), p.113.

[12] Chiyuan Gu, 2016; Design of Mobile Maps with Open Source Mapping Platforms

[13] Tony Wang, 2016; Design Guidelines for Designing Effective Mobile Pedestrian Navigation Systems; Science and Engineering Faculty Queensland University of Technology

[14] Montello, D.R. ed., 2001. Spatial Information Theory. Foundations of Geographic Information Science: International Conference, COSIT 2001 Morro Bay, CA, USA, September 19-23, 2001 Proceedings (Vol. 2205). Springer Science & Business Media.

[15] Montello, Daniel R., 2005. "Navigation". In: The Cambridge Handbook of visuospatial thinking. Ed. by P. Sha and A. Miyake. New York: Cambridge University Press, pp. 257–294.

[16] Roth, R. E., J. Van Den Hoek, A. Woodruff, A. Erkenswick, E. McGlynn & J. Przybylowski, 2009. The 21st century campus map: Mapping the University of Wisconsin-Madison. Journal of Maps, 5, 1-8.

[17] Petteri Nurmi, 2009, Identifying Meaningful Places, Department of Computer Science Series of Publications A Report A-2009-7

[18] Wenig, N., Wenig, D., Ernst, S., Malaka, R., Hecht, B. and Schöning, J., 2017, September. Pharos: improving navigation instructions on smartwatches by including global landmarks. In Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services (pp. 1-13).

[19] Perebner, M., Huang, H. and Gartner, G., 2019. Applying user-centred design for smartwatch-based pedestrian navigation system. Journal of Location Based Services, 13(3), pp.213-237.

[20] May, A. J., Ross, T., Bayer, S. H., & Tarkiainen, M. J., 2003. Pedestrian navigation aids: information requirements and design implications. Personal Ubiquitous Comput. , 7 (6), 331–338.

[21] Holone, H., Misund, G. and Holmstedt, H., 2007a, September. Users are doing it for themselves: Pedestrian navigation with user generated content. In The 2007 International Conference on Next Generation Mobile Applications, Services and Technologies (NGMAST 2007) (pp. 91-99). IEEE.

[22] Zhu, Y., 2012. Enrichment of routing map and its visualization for multimodal navigation (Doctoral dissertation, Technische Universität München).

[23] Huang, H. and Gartner, G., 2018. Current Trends and Challenges in Location-Based Services. ISPRS international journal of geo-information.

[24] Kapaj, A., 2018. User-Oriented Campus Routing (MSc thesis, Technical University of Munich).

[25] Dejen, S.T., 2018. Development of an Android Framework for Visual Navigation and Orientation (Doctoral dissertation, Politecnico di Torino).

[26] Mehigan, T.J. and Pitt, I., 2012, July. Harnessing wireless technologies for campus navigation by blind students and visitors. In International Conference on Computers for Handicapped Persons (pp. 67-74). Springer, Berlin, Heidelberg.

[27] Jacob, R., Zheng, J., Ciepłuch, B., Mooney, P., & Winstanley, A. C., 2009b. A Multi-lingual pedestrian navigation and campus guidance system using Cloud Made API. University of New South Wales, Sydney, Australia: University of New South Wales.

[28] Retscher, G., 2004, October. Pedestrian navigation systems and location-based services. In Fifth IEE International Conference on 3G Mobile Communication Technologies (pp. 359-363). IET.

[29] Huang, H., Gartner, G., Krisp, J.M., Raubal, M. and Van de Weghe, N., 2018. Location based services: ongoing evolution and research agenda. Journal of Location Based Services, 12(2), pp.63-93.

[30] Gartner, G., Frank, A.U. and Retscher, G., 2004. Pedestrian navigation system in mixed indoor/outdoor environment-the navio project. na.

[31] Groves, P.D., 2013. The PNT boom: future trends in integrated navigation. Inside GNSs, 8(2), pp.44-49.

[32] Gupta, S.K., 2016. Smartphone assisted pedestrian localization within buildings (Doctoral dissertation, University of Southampton).

[33] Brügger, A., Richter, K.-F., & Fabrikant, S. I., 2018. Which egocentric direction suffers from visual attention during aided wayfinding? In Eye Tracking for Spatial Research, Proceedings of the 3rd International Workshop (pp. 22–27).

[34] Daniel, M.P. and Denis, M., 1998. Spatial descriptions as navigational aids: A cognitive analysis of route directions. Kognitionswissenschaft, 7(1), pp.45-52.

[35] Siegel, A.W. and White, S.H., 1975. The development of spatial representations of large-scale environments. In Advances in child development and behavior (Vol. 10, pp. 9-55). JAI.

[36] Strelow, E.R., 1985. What is needed for a theory of mobility: Direct perceptions and cognitive maps—lessons from the blind. Psychological review, 92(2), p.226.

[37] Basaran Cabuk, 2018. Enhanced navigation and public transportation system for blind and visually impaired people, Tallinn University of Technology.

[38] Kozhevnikov, M., Hegarty, M. and Mayer, R.E., 2002. Revising the visualizer-verbalizer dimension: Evidence for two types of visualizers. Cognition and instruction, 20(1), pp.47-77.

[39] Mulloni, A., Seichter, H. and Schmalstieg, D., 2011, October. User experiences with augmented reality aided navigation on phones. In 2011 10th IEEE International Symposium on Mixed and Augmented Reality (pp. 229-230). IEEE.

[40] Giannopoulos, I., Jonietz, D., Raubal, M., Sarlas, G. and Stähli, L., 2017. Timing of pedestrian navigation instructions. In 13th International Conference on Spatial Information Theory (COSIT 2017) (Vol. 86, p. 16). Schloss Dagstuhl, Leibniz-Zentrum für Informatik GmbH.

[41] Borenstein, J., Everett, H.R. and Feng, L., 1996. Where am I? Sensors and methods for mobile robot positioning. University of Michigan, 119(120), p.27.

[42] Borenstein, J., Everett, H.R., Feng, L. and Wehe, D., 1997. Mobile robot positioning: Sensors and techniques. Journal of robotic systems, 14(4), pp.231-249.

[43] Hwan Hur and Hyo-Sung Ahn, 2009. Hybrid-style Wireless Localization Network for Indoor Mobile Robot Applications, in US-Korea Conference on Science, Technology, and Entrepreneurship, pp. 1-5.

[44] Lee, S. and Song, J.B., 2007, October. Mobile robot localization using infrared light reflecting landmarks. In 2007 International Conference on Control, Automation and Systems (pp. 674-677). IEEE.

[45] Burrows, D., 2013. Inclusive Landmark based Pedestrian Wayfinding via Multi-modal Directions.

[46] Andrienko, N. and Andrienko, G., 2006. Exploratory analysis of spatial and temporal data: a systematic approach. Springer Science & Business Media.

[47] Miller, H.J. and Han, J., 2009. Geographic data mining and knowledge discovery. CRC press.

[48] Karja, K., 2016. Visual Analysis of Origin/Destination Time Patterns of Travelers (Doctoral dissertation, Master's Thesis, TUM)

[49] Liu, L. and Zlatanova, S., 2013. Generating navigation models from existing building data. Acquisition and Modelling of Indoor and Enclosed Environments 2013, Cape Town, South Africa, 11-13 December 2013, ISPRS Archives Volume XL-4/W4, 2013.

[50] Koeppel, I., 2000. What are location services?-From a GIS perspective. ESRI white paper.

[51] Schiller, J. and Voisard, A. eds., 2004. Location-based services. Elsevier.

[52] Pricope, B., 2013. Positioning using terrestrial wireless systems (Doctoral dissertation, Technische Universität Hamburg-Harburg, Germany).

[53] Berg Insight AB, 2007. *Mobile maps and navigation (Market Research Report)*,

[54] Delikostidis, I. & van Elzakker, C.P.J.M., 2009b. Geo-Identification and Pedestrian

Navigation with Geo-Mobile Applications: Location Based Services and TeleCartography II, From Sensor Fusion to Context Models: Proceedings of the 5th International Conference on Location Based Services and Telecartography. Berlin Heidelberg: Springer-Verlag, pp. 185-206.

[55] Oulasvirta, A., Estlander, S. & Nurminen, A., 2009. Embodied interaction with a 3D versus 2D mobile map. Personal Ubiquitous Comput., 13(4), pp. 303-320.

[56] Gartner, G., Cartwright, W. and Peterson, M.P., 2007. Location Based Services and TeleCartography (Lecture Notes in Geoinformation and Cartography.

[57] Küpper, A., 2005. Location-based services: fundamentals and operation. John Wiley & Sons.

[58] Pielot, M. and Boll, S., 2010, May. Tactile Wayfinder: comparison of tactile waypoint navigation with commercial pedestrian navigation systems. In International conference on pervasive computing (pp. 76-93). Springer, Berlin, Heidelberg.

[59] Liu, L., 2011. Data model and algorithms for multimodal route planning with transportation networks (Doctoral dissertation, Technische Universität München).

[60] Kasemsuppakorn, P., 2011. Methodology and algorithms for pedestrian network construction(Doctoral dissertation, University of Pittsburgh school of Information Sciences)

[61] Pannevis, M., 2007. I'm Bored! Where is everybody? Location based systems on mobile phones? My Thoughts.

[62] Russo, D., Zlatanova, S. and Clementini, E., 2014, November. Route directions generation using visible landmarks. In Proceedings of the sixth ACM SIGSPATIAL international workshop on indoor spatial awareness (pp. 1-8).

[63] Kray, C., Elting, C., Laakso, K. and Coors, V., 2003, January. Presenting route instructions on mobile devices. In Proceedings of the 8th international conference on Intelligent user interfaces (pp. 117-124).

[64] Mathis, T., 2019. " Choose Your Own Route": Supporting Pedestrian Navigation Without Restricting the User to a Predefined Route (Doctoral dissertation, Geographisches Institut der Universität Zürich).

[65] Duckham, M. and Kulik, L., 2003, September. “Simplest” paths: automated route selection for navigation. In *International Conference on Spatial Information Theory* (pp. 169-185). Springer, Berlin, Heidelberg.

[66] Fallah, N., Apostolopoulos, I., Bekris, K. and Folmer, E., 2013. Indoor human navigation systems: A survey. *Interacting with Computers*, *25*(1), pp.21-33.

[67] Grum, E. and Frank, A.U., 2005. Risk of getting lost: Optimize a path to minimize risk. CORP, Vienna. Competence Center for Urban and Regional Planning.

[68] Mark, D.M., 1986. Automated route selection for navigation. IEEE Aerospace and Electronic Systems Magazine, 1(9), pp.2-5.

[69] Yen, J.Y., 1971. Finding the k shortest loopless paths in a network. management Science, 17(11), pp.712-716.

[70] Steck, S.D. and Mallot, H.A., 2000. The role of global and local landmarks in virtual environment navigation. Presence: Teleoperators & Virtual Environments, 9(1), pp.69-83.

[71] Sharkawi, K.H., Ujang, M.U. and Abdul-Rahman, A., 2008. 3D navigation system for virtual reality based on 3D game engine. Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Beijing, China, 37.

[72] Schaap, J., Zlatanova, S. and Van Oosterom, P.J.M., 2011. Towards a 3D geo-data model to support pedestrian routing in multimodal public transport travel advices. Urban and regional data management, UDMS annual, pp.63-78.

[73] Wen, W. and Hsu, S.W., 2005. A route navigation system with a new revised shortest path routing algorithm and its performance evaluation. WIT Transactions on The Built Environment, 77.

[74] Ujang, Muhamad Uznir and Abdul Rahman, Alias, 2008, Implementing shortest path calculation for 3D navigation system. In Advances toward 3D GIS. Penerbit UTM , Johor, pp. 153-164. ISBN 978-983-52-0584-12

[75] Jacob, R., Zheng, J., Ciepłuch, B., Mooney, P. and Winstanley, A.C., 2009, December. Campus guidance system for international conferences based on OpenStreetMap. In International Symposium on Web and Wireless Geographical Information Systems (pp. 187-198). Springer, Berlin, Heidelberg.