Towards a 3D geo-data model to support pedestrian routing in multimodal public transport travel advices

J. Schaap
9292 REISinformatiegroep bv, Utrecht, The Netherlands

S. Zlatanova & P.J.M. van Oosterom
Delft University of Technology, GIS Technology Section, Delft, The Netherlands

ABSTRACT: Current web-based multimodal travel planners are able to generate adequate travel advises for public transport journeys using timetable information, but they lack detailed pedestrian routing for the walking parts of a journey. This paper describes an approach to support pedestrian routing in multimodal travel advises. It focuses on a 3D data model to support finding of an optimal route for the individual public transport traveller taking into account his specific preferences and constrains (e.g. wheelchair) for the pedestrian part of the journey. Existing standards and models are explored to investigate approaches to develop such a 3D geo data model. An important characteristic of this 3D model is that no difference is made between indoor and outdoor spaces. The model is a combination of networks and surfaces with corresponding attributes and behaviour. The possible pedestrian connections are modelled by combining so called *NodeSurfaces* and *LinkSurfaces* to compute the possible routes. Attributes of *LinkSurface* such as the direction (including up/down in 3D), the accessibility and pedestrian duration for a specific traveller, support the computation of the optimal routes. A prototype using this new conceptual geo data model was implemented in Oracle 11g and results were visualized in Google Earth. Oracle Spatial 11g network shortest route capabilities for logical network are used for finding the optimal route for individual travellers with specific speed and accessibility properties. The developed prototype and performed tests have proven that this approach is very beneficial for enhancing the traditional journey timetables with routing for the walking part of the journey.

1 INTRODUCTION

Many countries offer travel planning websites for the public transport, e.g. the Dutch Door-to-Door Journey Planner (www.9292ov.nl), the German DELFI (www.delfi.de) the international EU-Spirit (www.eu-spirit.com). Such travel systems provide a travel advice with the most appropriate connections, given a departure/arrival time (Figure 1a). Some planners provide also a map for the walking part to a station or between stations (Figure 1b). Two deficiencies can be observed in such planners: 1) the journey planners use standard times for the walking part and 2) the possible routes inside stations are not indicated. The time is usually computed on the basis of an average walking speed. Many factors may influence the speed of walking and thus the time to move between public transports vehicles. The condition of the traveller (age, disability, etc.) and the geometry of the connection places are some of the most critical factors. During transfers, travellers have to find their way from the place of arrival to the place of departure of other means of transport. If the traveller is not familiar with the complexity of the transfer place, he/she might have difficulties with finding the correct exit (or correct platform), might get lost and finally miss the connection. Most commonly the traveller needs to claim stairs, wait for elevators, etc. when walking inside building, which also influences the moving time. The need for adequate information at the planning stage of a trip is of greater importance for a traveller using public transport than for a car. The planning stage of a public transport trip is an important stage to get familiar with transfer places especially when different kinds of transport modalities are used (e.g. bus and train) (Grotenhuis, et al. 2007).

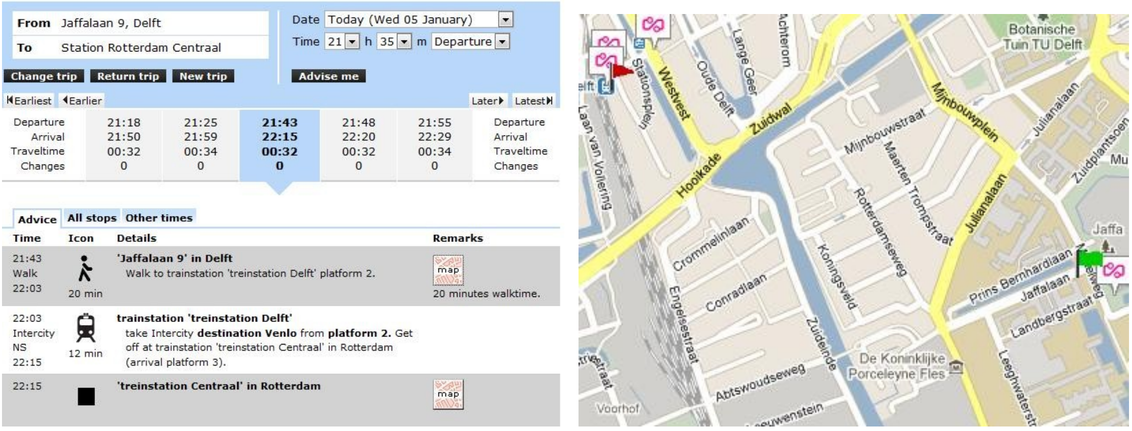

Figure 1. Result of travel advice of the Dutch Door-to-door journey planner: a) text, b) map for the walking part.

To overcome the above deficiencies various studies have been completed and models and standards have been developed. A very good example of these developments is the Identification of Fixed Objects in Public Transport model (IFOPT) accepted as European standard in 2007. As discussed in IFOPT, 2007, a good information system for Public Transport makes use of at least three groups of information about: fixed objects (bus stops, roads, stations), mobile objects (vehicles) and events (accidents, construction works). All this information is usually available by different providers and its up-to-date status, accuracy and completeness creates problems. IFOPT provides a model for the fixed objects. A lot of research has been conducted on modelling and wayfinding for pedestrians in transportation networks. Raubal and Worboys, 1999 developed a model that reflects the goal-driven reasoning chain that leads to taking a decision and performing an action. Hochmair, 2004 investigated 15 criteria that influence multi-modal travel, but the author concludes that a smaller set would be also sufficient. Rüetschi, 2007 and Rüetschi and Timpf, 2005 proposed a model for wayfinding in railway stations.

This work builds on the concept of (public transport) *Network Space* and (pedestrian) *Scene Space*. Important in this model is that the two spaces are defined and distinguished from each other by a set of specific properties, including differences in the level of scale, the wayfinding processes, the possibility to plan ahead, the role of time, and most important the intrinsic architectural building structure. It claims that any model of Scene Space must depend on Network Space and vice versa, because all pedestrian movement along routes in Scene Space is governed by spatial and temporal constraints established by Network Space and its public transport timetable schedule. This paper adopts these concepts but develops a different model to represent Scene Space for planning ahead pedestrian routing.

Clearly, the knowledge about the individual travellers and the specific geometry of transfer areas has to be taken into consideration in the individual travel advice. In this paper we argue that 3D information about the transfer place will be of a great benefit for the communicating explicit directions to the travellers. Realistic 3D visualisation showing walking directions added to travel advices gives the traveller the opportunity to prepare better himself for a walk in an unknown situation.

Three-dimensional (3D) GIS data models are studied for various applications. In research for emergency response in urban areas, evacuation and routing 3D data models are studied (Lee, 2004, Meijers et al. 2005, Miller 2006, Stoffel et al 2007, Hagendoorn et al 2009, Yuan and Schneider, 2010). Navigation inside and outside buildings is of vital importance in emergency situations and therefore various 3D data models are studied to support 3D routing. In this 'emergency response' research it is found that the 3D topological and graph models are best suitable for 3D routing. Construction of these topological and graph models is described in literature (Lee 2004, Stevens and Choi 2006).

However, research on 3D GIS data models in relation to public transport network models is still new. Visualisation of pedestrian routes in 3D GIS data models can improve travel advice from public transport information websites. Applications using 3D data models can help to prepare the traveller to find faster the way to the next public transport vehicle. A traveller could train himself for a transfer in an unknown situation with a simulated walk in a 3D visualisation. Adequate information in this preparation stage of a public transport vehicle exchange can substantially contribute to the overall satisfaction of multimodal public transport quality.

This paper is organised as follows: the next section defines the requirements on a 3D geo-data model to provide the information needed for pedestrian routing in multi-model transport context. In section 3 existing models are explored on the suitability to accomplish these requirements. No model was found applicable for our research, therefore an improved 3D geo-data model is proposed in section 4. Section 5 describes how this new 3D geo data model is implemented in a first prototype for pedestrian routing in our research. Finally conclusions are drawn and an outlook is given in section 6.

2 REQUIREMENTS TO THE 3D MODELLING OF THE SCENE SPACE

The traveller has different mental images when he is preparing a travel with a public transport compared to when he is planning a walk in a building or on the street (Rüetschi and Timpf 2005, Rüetschi 2007). When thinking of public transport, the traveller imagines a (public transport) network. This environment is dominated by connections made by transport lines (links) and the locations (nodes) where you can enter and leave or change the vehicles. It's the world of timetables, line maps, fare structures, alternative journey routes and sometimes delays. The public transport environment is called *Network Space* because it is based on the public transport node/link structure (Rüetschi 2007). This environment is created by strategic planners of public transport. The result of network design, planning and timetabling is designed to optimize travel times for the public. Very often it is influenced by historical, social, and economical processes.

The environment a traveller knows when he walks has a different origin. It is created by infrastructure and urban design. This walking environment is called a *Scene Space* (Rüetschi 2007). It is an environment for way finding. It has another type of structure, which is dominated by nested open spaces. Environments like stations (with its halls, squares, platform areas, etc.), airports, harbours, shopping malls, or public parks are samples of these walk environments. These environments are generally available in 2D but they have to be captured in a 3D geo-data model.

An effective and well-structured model of the 3D Scene Space is needed to support preparation of walking routing as part of a travel advice. The functional requirements for such a model can be specified as follows:

- Provide a sufficient number of objects to be included in the Scene Spaces
- Store spatial characteristics of objects relevant for pedestrian use of Scene Spaces
- Define accessibility constrains of Scene Spaces
- Combine indoor and outdoor Scene Spaces in one geo data model
- Connect Scene Space with the Network Space
- 3D visualisation of Scene Spaces.

In such a 3D model two kinds of structures can be created: *network* and *hierarchical*. 3D spaces when defined can be connected to each other creating a network topology of possible walking connections in Scene Space. For example an entrance is connected to a hall. A hierarchical topology of Scene Spaces exists because of the nesting of open spaces, e.g. a platform is part of a station. The network topology of Scene Spaces is important for accessibility and routing for pedestrians. The hierarchical topology is important for identification and visualisation of Scene Spaces to represent this nesting of open spaces.

The most import function of a journey planner is to help the traveller in preparation of his/her journey. Thus the traveller must be able to prepare himself for the pedestrian parts of a public transport trip. In the planning phase of a public transport trip the 3D geo-data model should be able to support this preparation. Consequently, several 'traveller's' requirements can be identified as well. An important element in his preparation is to identify the origin, the destination and the accessibility of the pedestrian parts. The pedestrian parts are needed to recognize the locations where egress of public transport vehicles in a journey takes place. Entrances and exits of public transport locations as part of a pedestrian route are important landmarks. Therefore a 3D geo-data model should have a structure to support the following functionality:

- Locate the entrance(s) and exit(s) of a public transport place in relation to the surroundings and the entry and exit points of public transport.
- Get detailed routing for access, transfer and egress of public transport.
- Get detailed routing inside and outside a public transport place
- Get detailed walk time and accessibility information for routing.
- Get proper 3D visualisation of routing

The representation of 3D Scene Space must be also able to accommodate large amounts of data (assuming it will be built for cities, countries or groups of countries) and to be practical to support the preparation of walking. These are implementation recommendations to arrive at a usable, well-structured geo-data model. In our research we have proposed the following guidelines:

- The geo-data model should be implemented in a spatial database.
- The 3D model should follow the semantic developments worldwide
- Apply when possible (Open or industry) standards in design and implementation

3 ANALYSIS OF EXISTING 3D MODELS

The above specified requirements were used to evaluate the existing 3D models and approaches in their suitability for modelling Scene Spaces. Some models are focusing on indoor navigation (Choi and Lee 2010) or interior construction details (buildingSMART), while other are having more focus on outdoor like CityGML (Gröger et al. 2008).

3.1 *The CityGML and IFC models*

CityGML LOD4 has information for indoor but is lacking detailed semantic objects relevant for pedestrian navigation for public transport. CityGML is extensible and adding these elements could form a good basis for pedestrian navigation related to public transport. Building Information Models (BIM) are used in construction work, these models are focussing on the indoor environment and on the construction details of facilities. BIM is a digital representation of physical and functional characteristics of a facility. Industry Foundation Classes (IFC, ISO PAS 16739) are a standard in this field. IFC represents a data schema for sharing construction and facility management data across various applications used in the building construction industry. It is a common exchange format in the field of architecture, engineering, and facilities management. It is an object-oriented data schema based on class definitions representing the objects (such as building elements, spaces, properties, shapes, etc.) that are used by different software applications used in construction or facility management project. There is also research on mapping elements from IFC to CityGML (Benner, et al. 2005, Isikdag and Zlatanova, 2009).

3.2 *The IFOPT model*

For Scene Space the IFOPT standard is very appropriate. The Fixed Object Model has a relationship to other standards describing the geographical features of a country, but it is not a GIS standard. The IFOPT Stop Place Model is strong in defining the semantic aspect, organizing, identifying and naming, of spaces relevant to support pedestrian navigation in relation to public transport areas. In the Stop Place model the entities from the passenger, vehicle and equipment domains are considered relevant to travellers:

- Vehicle area’s locations like tracks and stopping positions
- Equipment e.g. ticket machine, lockers
- Spaces which are publicly accessible (e.g. platforms, boarding positions ,entrances)
- Spaces (stores, kiosks, public toilets)

- Buildings/ part of buildings and indoor spaces
- Connecting elements between levels (steps, escalators, elevators, stairways ramps)

A weak point of the Stop Place Model is that it is a complex standard with a lot of classes, which however are lacking completeness. A "light" version of the standard which could be extended with local relevant elements would be easier to implement. However even in the current complex standard not all relevant items for travellers are included. For example signs are not included in the model. The signs are actively used for orientation. The location of these signs in relation to the footpath of the traveller must be in line with the descriptions of directions used in travel advises. Capturing all information from signs and their locations and direction in relation to the footpath will improve the information in travel advises. Furthermore 3D geographical aspects of objects are ignored in this standard.

3.3 *The Slingsby model*

In the model of Slingsby (Slingsby and Raper 2008) the pedestrian space combines geometric, semantic and navigation aspects. In this model 3D spaces are represented only by their lower surfaces. The objects described by the lower surfaces can have existence, accessibility, pedestrian direction and construction material attached as attributes. Some of these attributes are time-depended, while others are pedestrian-dependent. This model consist of 'barriers' (walls), 'portals' (doors and windows), 'teleports' (lifts) and 'spaces' (specific delineations of space). Persistent information is provided through lists of unique or recurring time periods (e.g. some barriers only exist at certain times of day). Using this information, the model attempts to incorporate some of the micro scale details of pedestrian access. A pedestrian has a step-height he or she is able to negotiate, which would be zero or very small for a wheelchair user. Although this model gives a good basis for a pedestrian model its semantics containing 'barriers' (walls), 'portals' (doors and windows),'teleports' (lifts) and 'spaces' (specific delineations of space) is not in line with semantics used in the field of public transport. However, the concept of lower, walking surfaces is adopted in our approach.

4 A 3D MODEL FOR SCENE SPACE

As illustrated above existing 3D GIS models are not directly suitable to support pedestrian routing to improve travel advice on public transport information websites. Some models focus on storing geometrical data while others on visualisation of this data, some models are a strong on the semantic aspects, others on supporting navigation. Therefore a new 3D data model to represent Network Space and Scene Space is proposed.

4.1 *The main concepts in the model*

The following concepts are taken into consideration (see Figure 2):

- *PublicTransportJourney* is the spatial and temporal constraints established in the Network space and in the Scene Space. It defines the entrance and access time and location to the public transport vehicles in a planned public transport trip.
- *Single space* is the smallest representation of a 3D indoor or outdoor public accessible area. A Single space can represent a real world space limited by physical borders or a logical part of a space limited for a specific purpose by unseen imaginary borders. Scale, time, pedestrian purpose and architectural structure of a Single space are influencing the borders. Single space can be limited by temporal or moving objects, e.g. doors, elevators or lifts. A *NodeSurface* models the lower surface of a Single space.
- The pedestrian connection of single spaces named *LinkSurface* defines how pedestrian entrance or exit of single space takes place. These connections define possible pedestrian movement (border crossings) in 3D between single spaces. They are describing the possible directions and accessibility of a pedestrian area and are modelling the accessible Scene Space.

- Pedestrian routes are the ways a traveller walks through a collection of connected Single spaces. The order of Single spaces determines the direction of pedestrian movement. The term pedestrian route is used to describe a path for all pedestrian movement followed by all kinds of individual or assisted travellers' locomotion by e.g. foot, wheelchair, dragging luggage, sleeping in a baby buggy. The representation of pedestrian routes is a *MultiSurfacePath* in the model.
- *TravellerProfile* is the selection of preferences on accessibility restrictions and speed of pedestrian movement chosen by traveller for a specific situation. These preferences are time and situation, public transport journey depending, various aspects are influencing these selection e.g. luggage, time pressures, physical efforts, safety, comfort, personal characteristics, habits, health concerns. This traveller profile defines the possibility to use a connection of single spaces and duration of pedestrian movement passing single spaces.
- *OptimalPedestrianRoute* is an accessible pedestrian route optimal in time (fastest) using the time and accessibility preferences from the travellers profile.

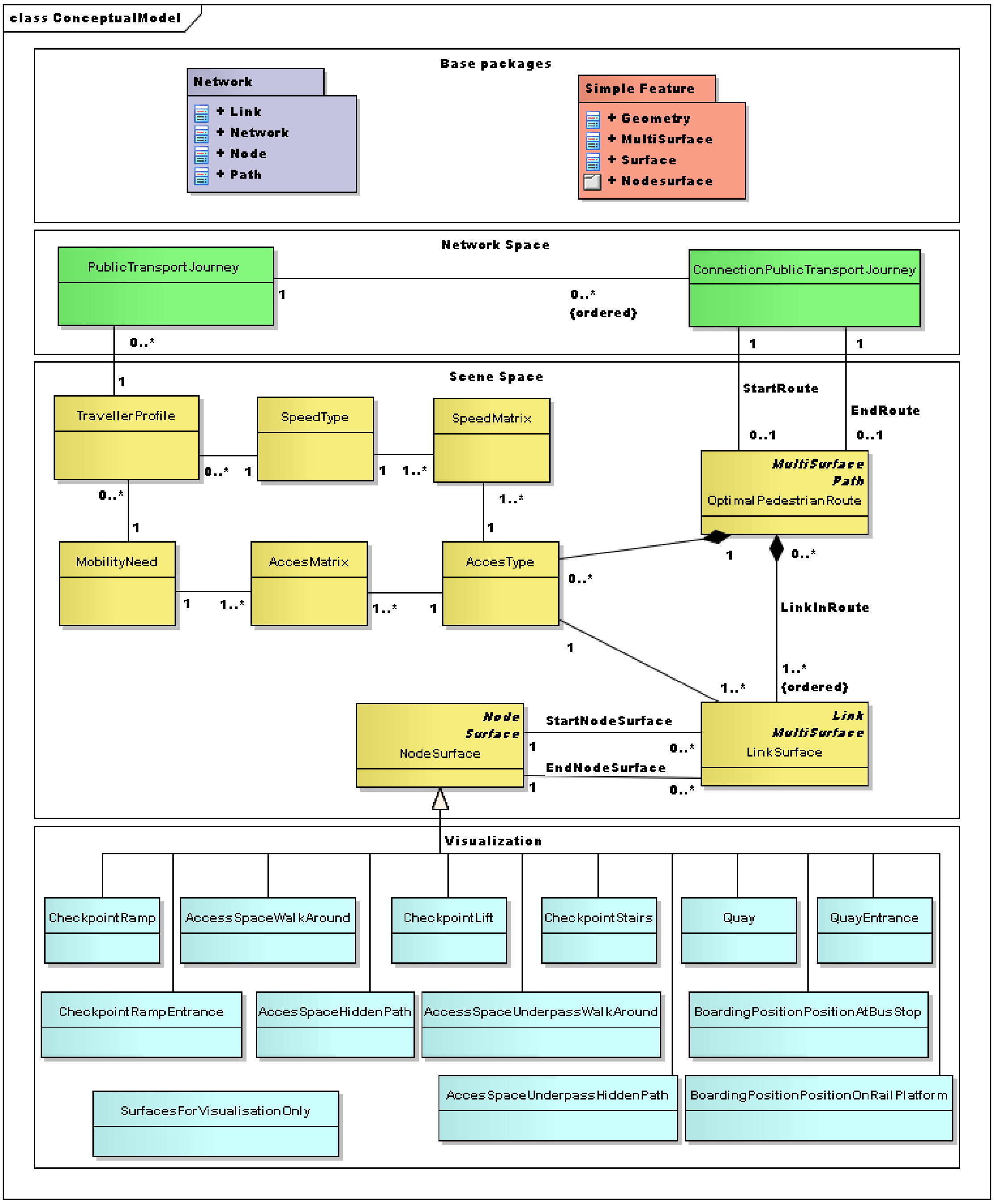

Figure 2. UML Overview class diagram of the conceptual model for pedestrian routing

The conceptual model is organized around the separation of Network Space and Scene Space and at the same time much attention is given to the visualisation. In Network Space only the spatial and scheduled temporal constraints created by planned public transport journeys are considered in this model, other important aspects in Network Space e.g. public transport line names, delays, disturbances or vehicle properties are covered in existing journey planners and not considered in this model. Scene Space is limited to 3D representation of accessible pedestrian areas relevant in the planning process of a walk as part of a public transport journey. To model this idea we separate core functionalities for Public transport, Pedestrian and Visualization. Other functionalities, Network and Simple Feature are considered base functionalities used as foundation in the conceptual model.

Figure 2 shows the UML class diagram of the conceptual model. In Base package the base classes of Network and Simple Feature are captured. The Pedestrian functionality is related to storing the geometry and finding optimal pedestrian routes for pedestrians. The pedestrian functionality uses the Simple Feature Implementation Specification for SQL (OGC 1999) as standard to store the spatial data. The other base functionality is Network. Network is used to model the pedestrian connections of Single spaces. The classes *Link*, *Network*, *Node* and *Path* in the Network functionality are needed to model a pedestrian route.

4.2 *The three packages in the model*

The Public transport package represents the public transport journey. Important are the locations were boarding and egress of the public transport vehicles takes place. Class *ConnectionPublicTransportJourney* models the locations where connecting vehicles entrances and exits locations to Single spaces take place.

The Pedestrian package captures the information related to the travellers. The traveller's preferences are given in the in the class *TravellerProfile*. The class *MobilityNeed* represents accessibility preferences to select in a profile. From the class *SpeedType* the preferences for modification of pedestrian movements speed are selected (e.g. Fast, Normal, or Slow). The class *NodeSurface* models the lower surface of a Single space. The *NodeSurface* is the generalization for all kind of Single spaces. The representation of pedestrian a connection is given with the class *LinkSurface*. *LinkSurface* represents the concept of a border between two Single spaces. It also specifies the direction of pedestrian movement over this border. The pedestrian connection of Single spaces is important for the accessibility of the next Single space in pedestrian movement. A classification of accessibility can be added to the combination of representation of Single spaces in a *LinkSurface*. This accessibility classification is captured in the class *AccesType*. To link this accessibility to the accessibility preferences in the travellers profile, the class *AccesMatrix* is defined. It holds the knowledge which preferred *MobilityNeed* are influencing the border that can be crossed by a pedestrian. The pedestrian connection of Single spaces is also important in the pedestrian speed moving over the next Single space. The class *SpeedMatrix* is linked to the *SpeedType*, which gives information which speed must be used to calculate the walk duration to the next a Single Space.

The Visualization package encompasses the objects relevant for the visualisation of the pedestrian navigation, combining visual and textual information and using the semantics derived from the IFOPT standard for the travel advices. The visualisation is used to distinguish between the different Single spaces and their purposes. Single spaces with different purpose are named differently. When applicable exiting names are derived from the IFOPT standard to further define a specific single space:

- *BoardingPosition* is a Single space where a traveller waits for boarding to a public transport vehicle.
- *AccessibleSpace* is a passenger area such as a concourse or booking hall, immigration hall or security area that is accessible by passengers, but without a direct access to vehicles Single space, may be a room, hall, concourse, corridor, or bounded open space.
- *Quay* is a Single space, such as platform or quayside where passengers have access to public transport vehicles, taxi cars or other means of transportation.
- *Checkpoint* is a Single space, which may potentially create an extra time penalty on top of the walk duration that should be allowed for when journey planning. Checkpoint is used IFOPT for processes like ticket control or immigrations. In this model it is also used for stairs, ramps, lifts and escalators.

4.3 *Refinement of a Single space*

To express the differences in Single Space between a real world space limited by physical borders and a virtual logical part of a space, a new terminology is created. The term *Walk around* is used for the Single space were a space is limited by real word visible borders and no specific pedestrian area is defined. With *AccesSpaceWalkAround* it is possible to explore the whole space, e.g. in a room of a museum or in square in a shopping area. Figure 4 illustrates the lower surface of one Single space modelled this way.

The term *Hidden* is used for a Single space with invisible borders in the physical world. If the purpose of a logical part of space is to define a logical walking area the single space is called *AccesSpaceHiddenPath*. The term '*hidden path'* is used because a logical walk area ('path') is supposed to exist in an open space, but this walkway is imaginary (or hidden) . Figure 5 illustrates the lower surfaces of two Single spaces modelled this way. Please note that modelling Single spaces is an abstraction process and borders of this kind of Single spaces are invisible in the real world. In this process scale is important and cartographic generalisation in 3D influences this process.

A similar approach to Slingsby and Raper 2008 is used to model the lower surfaces of accessible 3D spaces. However, the representation of logical links is different. In our model the logical links between a surface and its entrances and exits are modelled as the combined surface of the origin (*StartNodeSurface*) surface and the destination (*EndNodeSurface*) (see Figure 3).

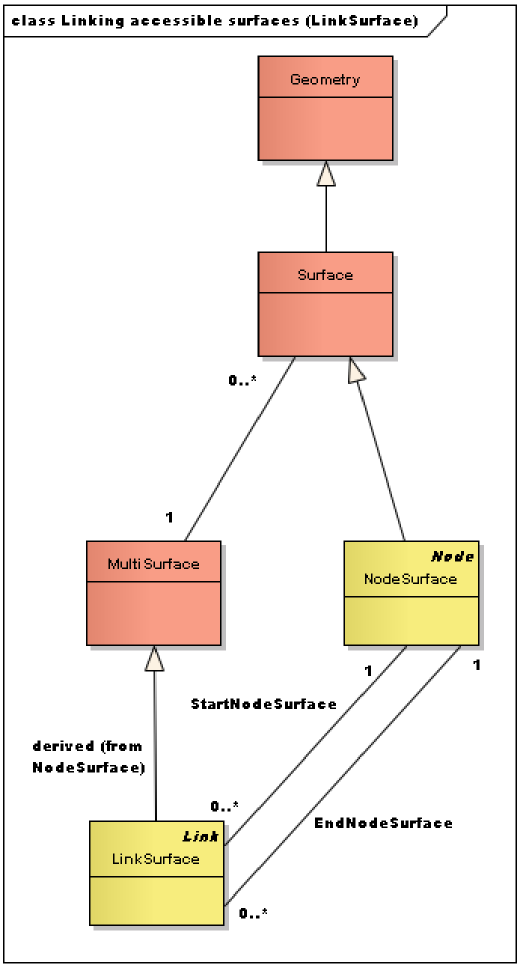

Figure 3. Class diagram showing LinkSurface as multiSurface and the start and end node roles

4.4 *Linking Network Space and Scene Space*

A link, called *LinkSurface* is a (derived) *multiSurface* geometry. The order of the surfaces is important in this *multiSurface* because it defines the direction of the link. The model restricts this *multiSurface* to a surface consisting of only two surfaces with only one connecting border. No disconnected surfaces are allowed in this *multiSurface*. This is done because route choice in this model is based on selecting relevant directions to unique entrances and exits of *NodeSurfaces*. Figure 4 is an example of a route choice after leaving the lift. After leaving the lift a central floor is reached (a *NodeSurface* indicated as *AccesSpaceWalkAround*). The possible directions are shown when leaving the *AccesSpaceWalkAround* to Ramp, to Escalator and to Stairs. These directions are shown as 'curtains' to represent better the possible pedestrian connectionss in Scene Space after leaving the *AccesSpaceWalkAroun*. To model the direction, a new surface is created by spatial union of the central floor (*AccesSpaceWalkAround* as *StartNodeSurface)* and the ramp surface (*CheckpointRamp* as *EndNodeSurface)*. This new surface (*LinkSurface)* models the pedestrian connection to the ramp from the central floor. This *LinkSurface* explicitly connects both surfaces and as such gives the walking (lower) surface of this pedestrian connection.

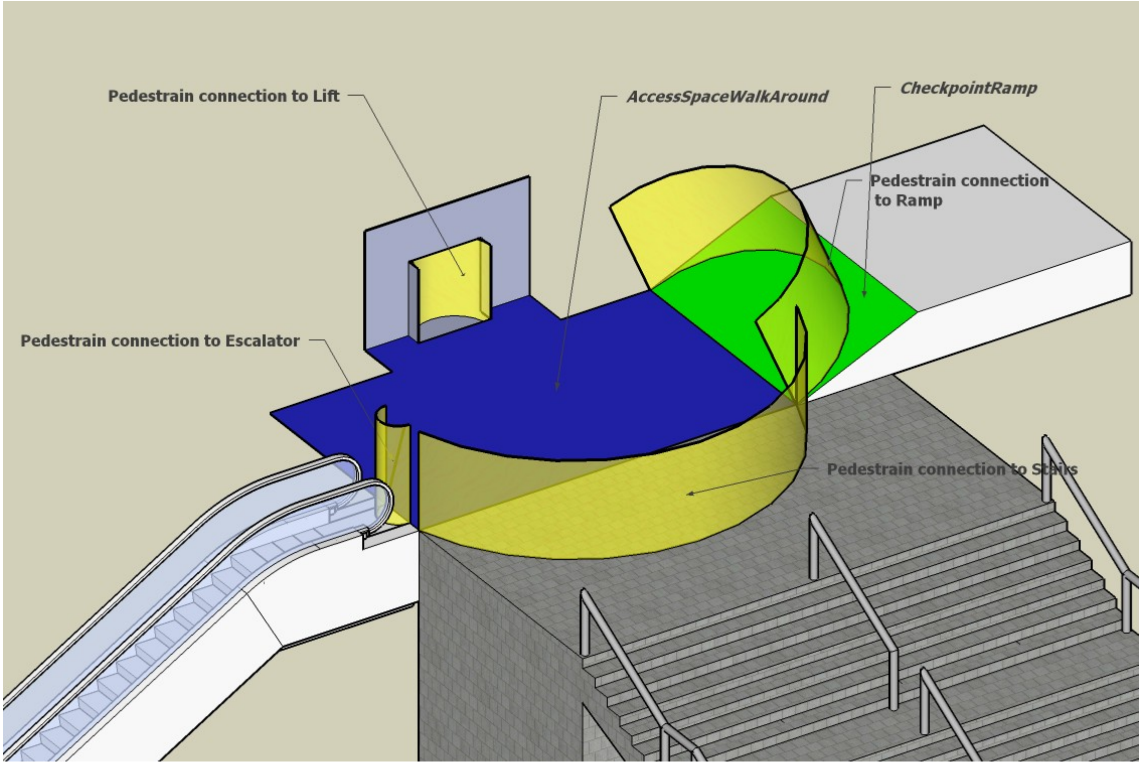

Figure 4. *AccessSpaceWalkAround* (the area at front of the lift), *CheckpointRamp* (te area towards the Ramp) and possible pedestrian connections to other *NodeSurfaces*.

The model is able to supports the concept of walking freely on a surface, *Walk around* and a more strict way of walking on *Hidden paths*. This manner of representation combines both ways of cartographic generalization of pedestrian routing. In Figure 4 the route a traveller follows when exiting the lift and walking to the ramp is not defined. The model supports the concept that the traveller walks freely to the ramp. This concept of free walking makes it possible to use only visible borders in the real world. For applications where more detail is needed, the model also supports the concept of logical walking routes in the Single spaces, i.e. *Hidden Paths*. When modelling *Hidden paths,* the *NodeSurfaces* are split in more detailed *NodeSurfaces*. The resulting *LinkSurface* is showed in Figure 5. Both ways of walks can be represented in the model.

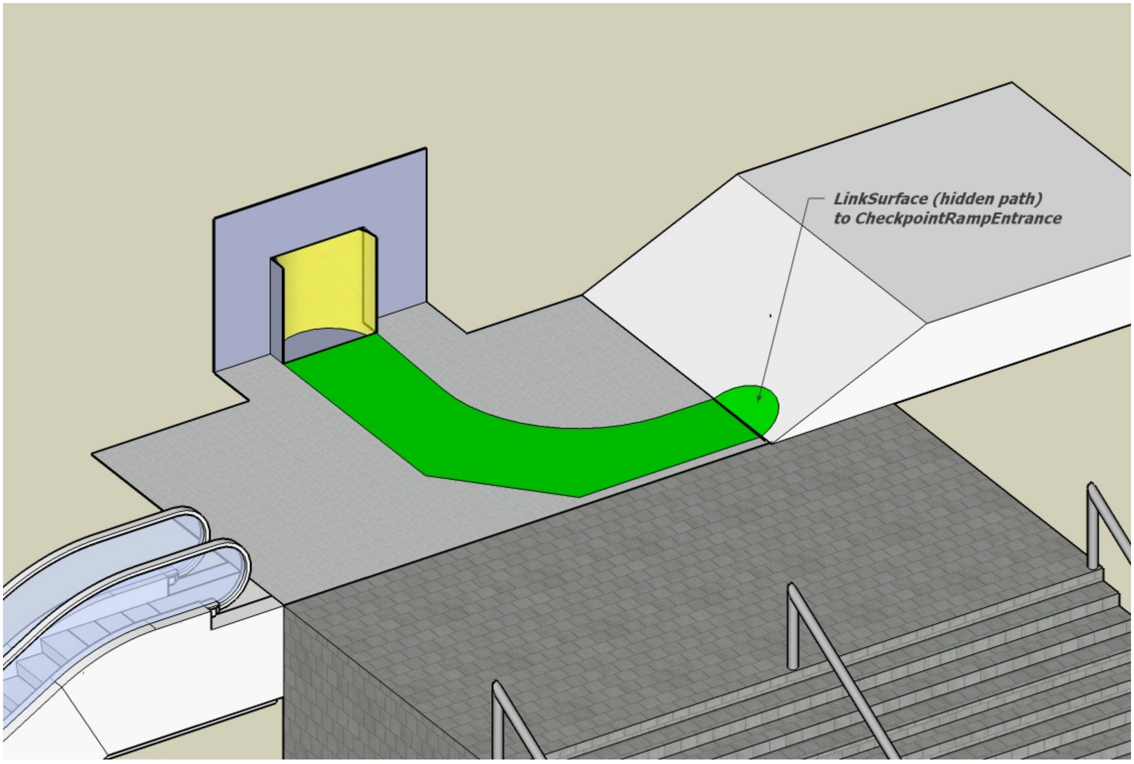

Figure 5. *Hidden path* and *hidden ramp entrance*

4.5 *Accessibility restrictions and the individual traveller*

The *LinkSurfaces* are categorized in different access types. The visualisation class of the *EndNodeSurface* in combination with the relative height of two *NodeSurfaces* determine the acces type of the *LinkSurface*. In Figure 5 the ramp is located relative higher than the *NodeSurface* and is connected to the lift therefore the type of the *LinkSurface* is 'Ramp-Up'. These access types are used as accessibility restrictions for the *LinkSurface*. Furthermore they are used to add pedestrian duration as attribute to the *LinkSurfaces*.

These accessibility restrictions in are direct mapped to possible individual traveller needs as shown in Table 1. The semantics for these attributes are derived from the IFOPT standard (IFOPT 2007).

Table 1. Individual needs (*MobilityNeed*) related to accessibility (*AccesType*) of a *LinkSurface*

	No restriction	Single Step (Up Down)	Ramp Up	Ramp Down	Stair Up	Stairs Down	Lift	Escalator Up	Escalator Down
Wheelchair	Y	N	Y	Y	N	N	Y	N	N
Step Free	Y	N	Y	Y	N	N	Y	Y	Y
Averse to lifts	Y	Y	Y	Y	Y	Y	N	Y	Y
Escalator free	Y	Y	Y	Y	Y	Y	Y	N	N
Luggage heavy	Y	N	N	N	N	N	Y	Y	Y
Luggage medium (no stairs ramps up)	Y	Y	N	Y	N	Y	Y	Y	Y
No down stairs/ramps /escalators	Y	N	Y	N	Y	N	Y	Y	N

All *LinkSurfaces* compose the pedestrian network. The combination of access restrictions and pedestrian duration makes it possible to calculate optimal walk routes with a given transfer point in public transport. In the model the pedestrian accessible surfaces (*NodeSurfaces*) are modelled as objects, which inherit attributes and behaviour from nodes in a network. Figure 6 illustrate the classes of the network package, i.e. *Path*, *Link* and *Node*. The *Optimal Pedestrian Route* is then a specialisation of *Path* and the *LinkSurface* is a specialisation of *Link* in the network. The relations between *NodeSurface*, *LinkSurface* and the navigational path for the optimal pedestrian route are shown as well.

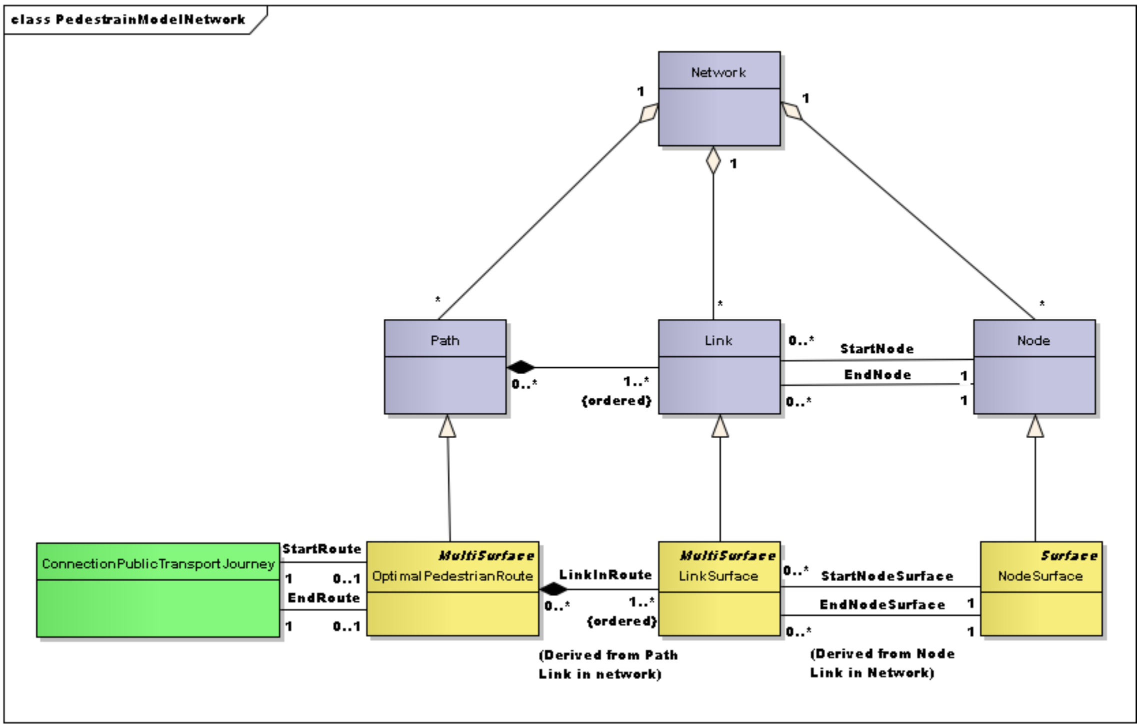

Figure 6. Class diagram surfaces are modelled as objects inherit attributes and behaviour from nodes in a network

The necessity to connect public transport with pedestrian routing is illustrated by the possibility to connect *ConnectionPublicTransportJourney* and *OptimalPedestrianRoute* classes. Connecting boarding and egress locations of public transport vehicles, in a public transport advice, to an optimal pedestrian route is done though the start- en end- *NodeSurfaces*. An *OptimalPedestrianRoute* is an ordered collection of *NodeSurfaces*. The start *NodeSurface* is defined as the first *NodeSurface* in the sequence of an optimal route and the end *NodeSurfaces* as the last *NodeSurface*. More details on the model and the implementation can be found in (Schaap 2010).

5 PEDESTRIAN ROUTING WITH THE MODEL

Using this model and the classes related to the *TravellersProfile* (see Figure 2), an optimal pedestrian route can be calculated.

5.1 *Computing the optimal path*

To enhance a standard public transport travel advice with walk routing for a traveller having a specific travel profile the following steps must be taken:

1. Optimal navigational path calculation starts with deriving the start en origin from the walk parts from a public transport travel advice. These start and origin points must be matched on *NodeSurfaces* describing these points. (E.g. IFOPT Boarding positions, entrance or public places). Connecting boarding and egress locations of public transport vehicles is done though the start- en end- *NodeSurfaces* in an optimal pedestrian route.
2. The *TravellerProfile* is composed. The walk *SpeedType* in combination with the individual *MobilityNeed* from the traveller is defined for this traveller.
3. With the individual *MobilityNeeds* from the *TravellerProfile*, a sub-selection of all *LinkSurfaces* is made containing all *LinkSurfaces* this traveller can possibly use in an optimal path.
4. For the set of *LinkSurfaces* selected for the *TravellerProfile*, the walking durations are assigned to each *LinkSurface* according to the profile. This duration is calculated for each *LinkSurface*.
5. After the construction of this set of *LinkSurfaces*, fitting this *TravellerProfile* the fastest path (shortest path in time) is calculated between *StartNodeSurface* of the *StartRoute* and start and *EndNodeSurface* of the *EndRoute*.
6. Different navigational paths with the same total walk duration can be found as fastest path. In this case both are seen as an optimal solution and one of these navigational paths is selected at random to represent the *OptimalPedestrianRoute*. It is also possible that for this individual user the destination is not reachable.
7. If a destination is not reachable, a new *PublicTransportJourney* must be generated avoiding this walking part. Because of pedestrian constraints the destination of the walk part might be not reachable in time to connect to public transport. Also in this case a new public transport advice must be generated using the new departure time at this boarding position. The steps 1 till 6 are repeated for each walk part of a *PublicTransportJourney* .
8. After *OptimalPedestrianRoutes* are found for all walk parts of a *PublicTransportJourney*, a public transport advice is created including pedestrian routing. The *OptimalPedestrianRoutes* found for this travel advice can be used for textual walk times and accessibility and route information.

The steps are implemented in our prototype.

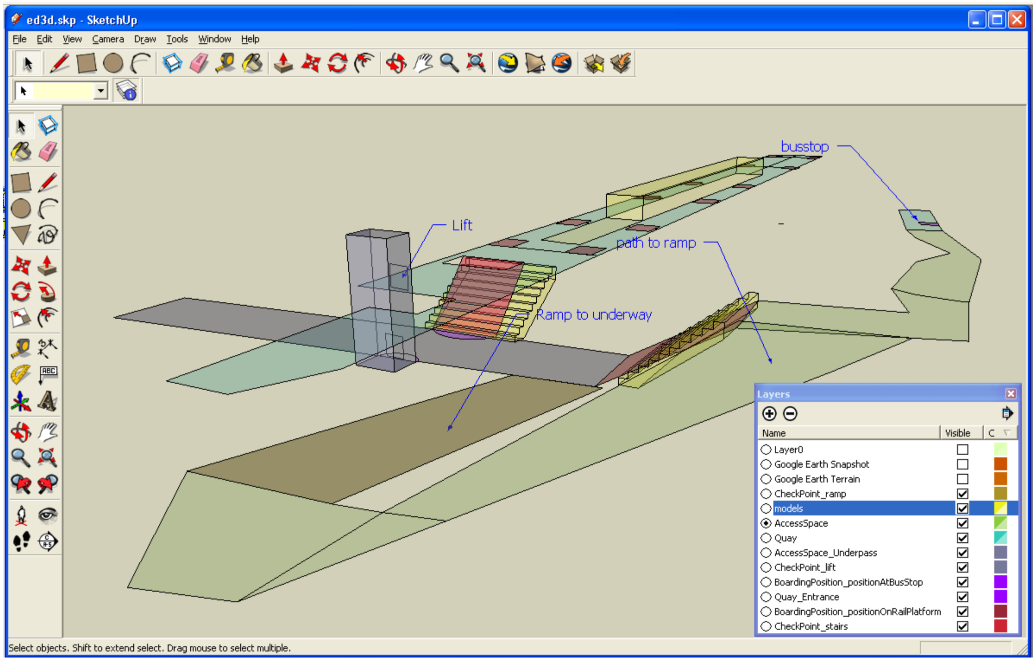

Figure 7. *NodeSurfaces* for studied location Ede-Wageningen in Google SketchUp

5.2 *Implementation*

The model was implemented Oracle Spatial 11g. The visualisation was done in Google Earth. Relevant data for the model were manually created in Google SketchUp and exported to KML files. Figure 7 shows the Google SketchUp model for the test location (i.e. the railway station of Wageningen, the Netherlands).

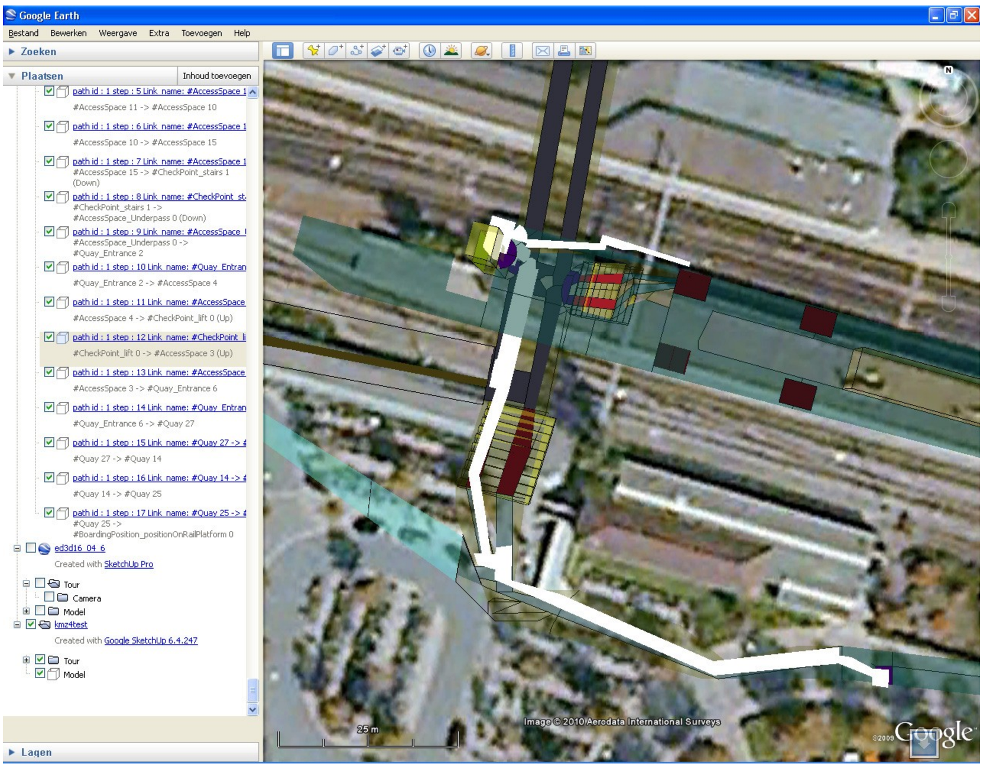

Figure 8. Walking route between bus stop and entrance of a train.

This dataset was constructed to illustrate and validate the proposed geo-data model with Scene Space from a transfer location with indoor and outdoor Single Spaces, Multi model complexity (bus and train stops) and 3D Scene complexities with specific access constrains (Underpass, Stairs, Ramp and a Lift). The tested transfer location is not very complex. The evaluated public transport journey assumed transfer from bus to train. For a traveller with local knowledge and no restrictions, an optimal route can be straightforward found. The restricted traveller needs to use a ramp and/or a lift (based on his traveller profile). In the test model, people not able to use stairs have to consider the ramp down to the under passage at the left hand when entering the south entrance. Furthermore there is a lift in the underpass to the platform. This lift is located opposite of the stairs to the platform in the underpass (Figure 7).

Our first test focussed on traveller's profiles with different pedestrian movement speed (Fast, Normal and Slow). The second test included accessibility needs (No specific needs, Wheelchair, Step Free, Averse to lifts, Escalator free, Luggage heavy, Luggage medium and No down stairs/ramps).

5.3 *Testing*

The first pedestrian routing without accessibility restrictions revealed some limitations in the prototype when the Scene Space was modelled with only *WalkAround* Single spaces. The used distance calculation algorithm in the prototype, based to half the perimeter of the *NodeSurface*, was not precise enough to be useful for optimal pedestrian routing (but quite crucial in optimal route computation). Furthermore wrong pedestrian connections were created at certain locations along pedestrian routes due to the limited 3D intersection capabilities of Oracle Spatial 11g. The Oracle Spatial 11g offers only ANYINTERACT between two surfaces in 3D. The operator SDO_RELATE with various masks to test for the different kind of spatial relations is available only for 2D geometries (Murray 2010). In further evaluation of the prototype the problematic Single spaces were redrawn using *Hidden* path and *NodeSurfaces* to overcome these limitations.

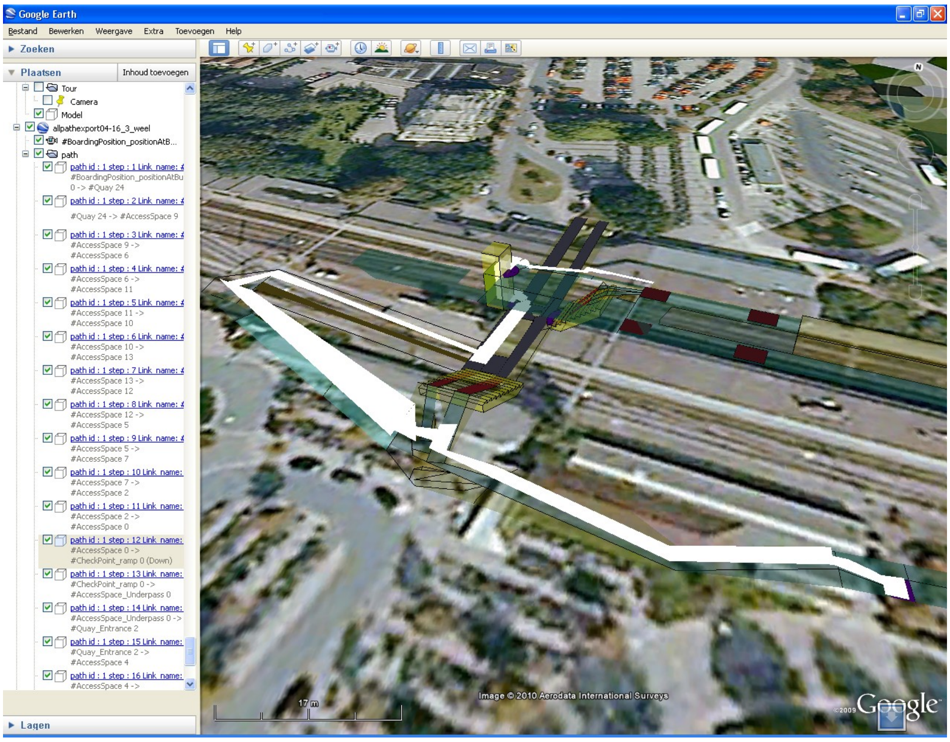

Figure 9. The optimal route between the bus stop and platform (and entrance) of a train for travellers who cannot use stairs, heavy luggage or wheelchair.

The overall results of tests were promising: it was possible to find optimal pedestrian routes with respect to the tested traveller's profiles. Figure 8 illustrates the optimal route between the bus station and the needed train platform. Restricted pedestrians use the ramp as indicated in Figure 9. They have to use ramp down to underpass and the lift up to Quay.

6 CONCLUSION AND OUTLOOK

This paper describes a novel 3D geo-data model of accessible pedestrian spaces in 3D to support pedestrian routing in multimodal public transport travel advices.

6.1 *Main Results*

Innovative aspects in this geo data model are:

- The model manages information about the walk duration preferences for specific travellers by the traveller's profiles. This information addresses the first disadvantage of journey planners, i.e. the standard time used for walking.
- The model to represent the Scene Space incorporates accessibility and 3D spatial characteristics. This model allows a connection between the Scene Space and the Network Space. Thus this approach provides a solution to the lack of information about transfer places in current journey planning systems.
- The concept of *NodeSurface* and *LinkSurface* to represent Scene Spaces is a simple, effective and yet well-structured way to represent complex spaces used by pedestrian routes in a geo data model.

Furthermore the model supports the concept of walking freely on a surface, i.e. *Walk around* and the more strict way of walking on *Hidden paths* over surfaces. This can be used to have differences in conceptual generalization when modelling pedestrian routing in visualisations at different scale.

The overall results of the prototype were promising especially when modelling *Hidden paths*. It was possible to implement the geo data model in Oracle Spatial 11g. Oracle Spatial 11g network shortest route capabilities for logical network turned out to be suitable for finding the optimal route for individual travellers with specific speed and accessibility properties.

6.2 *Future work*

The tests are still of limited complexity and the model needs further research towards the feasibility and suitability of this new model for different transfer points. Currently no tests with escalators and complex lift situations are completed. The algorithms should be further elaborated to define more efficiently hidden path areas is useful to limit labour when modelling complex public transport places.

Visualisation of the results could also be improved. Better visualisation of pedestrian routing is needed including underground objects in a clear way. As known, Google Earth does not provide underground visualisation yet. Integrating sign information in the pedestrian model and improved visualisations are needed to be included on travel information websites.

Websites with travel information for public transportation must be able to generate travel advises fast and in large amounts. The prototype did not focus on performance and scalability aspects. The separation of logical steps (i.e. link assigning according to traveller needs, network loading and route calculation, storing and visualisation) need to be reconsidered when developing a scalable and fast website applications. Performance could be improved by keeping the pedestrian network in memory for all optimal route requests. A dedicated software program specific written for this functionality could optimize this process and outperform the Oracle network search capabilities used in the described prototype.

Applications using the proposed geo data model are not limited to applications for trip preparation. Future applications on mobile devices with adequate indoor and outdoor positioning could use the proposed geo data model to facilitate travellers during a transfer. Showing directions in real-time on mobile devices could guide travellers to the next public transport vehicle. These applications could be very sophisticated. An application might show a virtual guide, e.g. a guide dog, projected over an image of the actual environment: augmented reality based (similar to Layar for outdoor applications). The symbolisation of speediness of the virtual guide in such application could inform the traveller to hurry to catch the next vehicle. The symbolisation of speediness could be based on the real-time departure times of vehicles and the expected walk distance in the geo data model. Lack of adequate indoor positioning in mobile devices and detailed 3D datasets of pedestrian locations is currently limiting these developments, but it is most likely that these (indoor positioning infrastructure and detailed 3D datasets) will be available in the future.

The 3D spatial data sets describing pedestrian locations were constructed based on aerial photos and existing map of these locations. This way of constructing 3D spatial datasets for pedestrian routing is time-consuming and prone to errors. More efficient ways of capturing and collecting spatial information of 3D data to support pedestrian routing in public transport advices on a national scale must be found. Tools to automatically create pedestrian surfaces from existing indoor building models (IFC or CityGML LOD4) could be beneficial in the creation of these datasets. Agreements on collection, exchange and maintenance of these 3D spatial data are important between the involved parties.

A spatial data infrastructure (SDI) supporting pedestrians routing around public transport is essential for this. The proposed conceptual model could be used as basis for a data exchange format in such a SDI. In this respect a research on the establishment of a spatial data infrastructure (SDI) for this would be a step towards a 3D geo-data model solution to support pedestrian routing in multimodal public transport travel advices on a national scale.

ACKNOWLEDGEMENTS

The authors of this paper want to express their gratitude to the anonymous UDMS reviewers for the constructive comments. This research was conducted in the context of the MSc GIMA thesis project of the first author (Schaap 2010).

REFERENCES

Benner, J., Geiger , A. and Leinemann, K., 2005. Flexible generation of semantic 3D building models, Proc of the 1st Intern. Workshop on Next Generation 3D City Models.

Choi, J. and Lee, J., 2010. 3D Geo-Network for Agent-based Building Evacuation Simulation. In: Showalter and Lu (eds.), Geospatial Techniques in Urban Hazard and Disaster Analysis Geotechnologies and the Environment, 2010, Springer Volume 2, Part 5, 415-429

Gröger, G., Kolbe, T.H., Czerwinski, A. and Nagel, C., 2008. OpenGIS City Geography Markup Language (CityGML) Encoding Standard, Version 1.0. 0, International OGC Standard. Open Geospatial Consortium.

Grotenhouse, J.W., Wiegemans, B.W. and Rietveld, P., 2007. The desired quality of integrated multimodal travel information in public transport: Customer needs for time and effort savings, Transport Policy, 14(1), 27-38.

Hochmair, H., 2004. Towards a classification of route selection criteria for route planning tools, Developments in Spatial Data Handling, Springer, Berlin, 481-492.

Hagedorn, B., M. Trapp, T. Glander and J. Dollner, 2009, IEEE Computer Society, pp. 692-697

IFOPT, 2007, Road traffic and transport telematics Public transport Identification of Fixed Objects in Public Transport, Technical Specification, CEN/TC278, University Zurich. 144p.

Isikdag, U and S. Zlatanova, 2009, A SWOT analysis on the implementation of BIM within geospatial environment, in Krek, Rumor, Zlatanova & Fendel (eds.) Urban and Regional data Management, UDMS Annuals 2009, CRC press, Boca Raton, pp. 15-30

ISO PAS 16739, 2008 Industry Foundation Classes Release 2x, http://www.iso.org/iso/iso_catalogue/ catalogue_tc/catalogue_detail.htm?csnumber=38056

Lee, J. (2004). A Spatial Access-Oriented Implementation of a 3-D GIS Topological Data Model for Urban Entities. *Geoinformatica* 8(3): 237-264.

Meijers, M., S. Zlatanova and N. Preifer (2005). 3D geoinformation indoors: structuring for evacuation, in: *Proceedings of Next generation 3D city models*, 21-22 June, Bonn, Germany, 6 p.

Miller, L. E (2006). Indoor Navigation for First Responders-A feasibility Study ,NIST Report, Available online at: http://www.antd.nist.gov/wctg/RFID/Report_indoornav_060210.pdf

Murray, C., 2010. Oracle® SpatialDeveloper's Guide11g Release 2. March 2010 edn. Redwood City: Oracle Corporation.

Schaap, J. (2010) Towards a 3D geo-data model to support pedestrian routing in multimodal public transport travel advices Master's thesis GIMA (Utrecht Univ., TU Delft, Wageningen Univ., ITC), 2010, 101 p.

Slingsby, A. and J. Raper (2008). Navigable Space in 3D City Models for Pedestrians, in: Van Oosterom, Zlatanova, Penninga&Fendel (eds) *Advances in 3D Geoinformation Systems*, Springer, Berlin, Heidelberg, pp. 49-64

Stoffel, E., B. Lorenz and H. Ohlbach (2007). Towards a Semantic Spatial Model for Pedestrian Indoor Navigation. In Hainaut, J., Rundensteiner, E., eds.: *ER '07 Workshops / Advances in Conceptual Modeling*, Springer, 328–337.

Stevens M. and J. Choi, 2006. CAD Data Conversion to a Node-Relation Structure for 3D Sub-Unit Topological Representation. Journal of the Korean Geographical Society, 41(2), pp188-194.

Raubal, M. and M. Worboys, 1999, A Formal Model of the Process of Wayfinding in Built Environments, in: Freksa & Mark (Eds.): COSIT'99, LNCS 1661, Springer-Verlag Berlin Heidelberg, pp. 381-400

Rüetschi, U.J., 2007. Wayfinding in Scene Space Modelling Transfers in Public Transport, Dissertation, University Zurich. 137p.

Rüetschi, U.J. and Timpf, S., 2005. Modelling wayfinding in public transport: network space and scene space. Spatial Cognition IV, pp. 24-41

Yuan, W. and M. Schneider, 2010, Supporting 3D route planning in indoor space based on the LEGO representation, ACM, ISA'10, 2 November 2010, San Jose, CA, USA, 8 p.