sDNA Pedestrian Network Recommended Spec v2.0

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1   Preamble

As a precursor to creating large scale, 3d pedestrian network and using sDNA 3D to analyse it, it is necessary to:

1. Define a standard format, a data model that maximises the ease of creation and automatic data model verification.
2. Delineate the "round trip" procedure between sDNA ArcGIS and urban design CAD software (Autodesk Map3d).

This document is a step towards the definition of the data model, necessarily incomplete at this stage, but it is hoped that pilot projects that involve network generation will adhere to it so the data model can be further refined.

This specification is not sacred. QUESTION EVERYTHING! Does it seem sensible?

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Several well-known 2d network mapping products exist in the UK: OS Meridian, ITN, Urban Path. There is also ISO 14825, for intelligent transport networks such as those used in satellite navigation systems. None of these have been designed with complex 3d model creation and checking in mind. The aim of this document is not to compete with these, but to define a format in which detailed 3d networks can be reliably and easily created. Once a reliable network exists, it can be converted to match existing standards e.g. by automatically adding nodes.

We propose that in a fully 3d model, links should be encoded directly as 3d polylines. This is in contrast to the above cited studies, in which elevation is attached to nodes (Meridian), link ends (ITN) or encoded as a separate relational data ('Brunnels' in ISO14925).

2   File Format

It is envisaged that a large scale spatial model will be split into numerous submodels (Fig. 1), representing

- Network outside buildings
- Network inside buildings
- Network for individual floors of buildings
- Network for transit systems such as railway, LRT, tram, road, bus…
- A specification of how the networks fit together
- A separate network model of the road network, for reference

Any format used for 3d networks must

- be fully spatially geo-referenced, with the different sub-models encoded according to the same spatial reference,
- allow encoding of 3d polylines (line features having no width) and nodes (point features having position but no extent), both with attached data.
- be convertible to the open ESRI 3d Shapefile format (with z data attached) for analysis
- be used in accordance with the Topology Rules given below, to enable automatic verification

Currently we recommend using the Shapefile format itself for creating and editing networks. We have been investigating interoperability with BIM formats (Vasari/Revit) in particular using Industry Foundation Classes (IFC)[1]; however, Autodesk BIM currently does not support the creation of road and path networks. For the time being, therefore, it is proposed to integrate with urban design workflows using CAD (Map3d) rather than BIM.

Some formats (not including shapefiles) allow specification of different layers within a single file. The designer may at their discretion, keep several layers in one file (e.g. different floors of a single building, or different buildings within a city centre. Note that layers do not necessarily have to share the same elevation – this is consistent with Autocad usage of the term). We use the term *layer* throughout this document even though some file formats do not support multiple layers. For such formats, 'layers' must necessarily be stored within separate files. Where files do support multiple layers, the designer is free to group multiple layers into a single file or set of files at their discretion.

We also recommend that layers and files are named such that all named begin with the layer type: PFN, PIN, PON, PTN, PCN, PAN. Ideally this information would be stored elsewhere than the filename, however we make this choice to maintain compatibility with shape files.

3   Definition of network link

A link is the longest component of a spatial network that can be traversed without having to make a route choice. In other words, a link either joins

1. two junctions
2. a junction to a dead end
3. a junction to itself

Note that what is typically perceived as a single path, corridor or stairway may comprise a sequence of many separate links joined at their endpoints, as links must always terminate at junctions. Outside *streets* will contain even more links, as the various pedestrian paths (sidewalks) must be provided individually. For our purposes we standardize on the network link as an atomic object of network composition, except where otherwise stated below.

4   Topology rules

For the following discussion we distinguish between 3d intersections (lines which meet, within a certain tolerance) and 2d intersections (lines which appear to intersect from plan view, but may in fact be at different positions on the z axis).

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[1] IFC is an object-oriented database of information that enables data sharing via ifcXML and aecXML. IFC-compliant applications can import IFC files and (re)use 'intelligent' data created in other IFC-compliant application, and export 'intelligent' model information as IFC files for (re)use in other applications. IFC are the 'lowest common denominator' of all involved applications, therefore, high-end functionality in some applications is being reduced to the level of functionality that all applications can support.

So-called 'round tripping' of IFC data, i.e. importing an IFC-file into the application which exported it or any other IFC-compliant application without any loss of data or functionality, is neither a current objective of the IFC2x3 Extended Coordination View nor a certification criteria, requirement, or use case.

4.1   Rationale

Irrespective of file format, we require all networks to adhere to topology rules. The goal of these rules is to decrease the likelihood of the following classes of error going undetected:

1.   accidental 3d intersection, when lines should be broken at an intersection
2.   lines which (depending on the 3d view position) may appear to be joined when they are not
3.   lines which (depending on the 3d view position) may join to the wrong line, for example, in plan view a line directly above/below the intended line

Any errors of these types that appear in a spatial network could potentially have a disastrous effect on the analysis: spatial network analysis is reliant on highly accurate network topology.

However, an equally important goal of these rules is to make the designer's job easier. Not only do they enable a more organized workflow, with frequent automated error checking, but they also allow for automated editing processes to be used by defining contexts in which they will work. For example, as 2d intersections are prohibited in both PFN and PON, the designer may at their choice use a tool such as ArcGIS Planarize or Map3d Drawing Cleanup to break all 2d intersections in a PFN or PON layer. This allows for exterior network or interior floorplans to be drawn intuitively (i.e. with multiple intersecting lines) and convert to a spatial network model, in which links are broken at intersections, after the drawing phase.

Although the networks must adhere to a set of topology rules, this set of rules is not final. Please discuss requirements with us.

4.2   Types of layer

Note that different situations require different rules. For example, an exterior network will rarely contain 2d intersections (only bridges and tunnels). Within a building, on the other hand, 2d intersections are very common. Within a single floor of a building (as we define it), links never contain 2d intersections at all.

For this reason, and also to reduce the complexity of the editing task, we specify that networks must be created in separate files/layers:

1.   one or more files/layers for the pedestrian outside network (PON) – path, crossing etc
2.   one or more files/layers for the pedestrian inside network (PIN) – entire buildings
3.   one or more files/layers for the pedestrian floor network (PFN) – single building floors
4.   one or more files/layers for the Public Transport Network (PTN) – e.g. rail system
5.   (optional) one or more files/layers containing combinations of the above, merged together, as part of building a larger model. These are known as Pedestrian Combined Network (PCN).
6.   (compulsory for finished network only) one file/layer which contains all the network (Pedestrian All Network - PAN)
7.   (optional) one of more files containing the Vehicle Transport Network (VTN) for reference only, and not to be included in the model.

The choice of whether to model a given building as a PIN, or as PIN+PFN is left to the designer, as the most appropriate choice will depend on the individual building. For buildings with complex layouts for floors other than the ground floor (such as some shopping centres) PIN+PFN may be most appropriate. For buildings where non-ground floors have a simple layout (such as a subway station) PIN alone may be preferable.

As a PIN can represent only a single building, and a PFN only a single floor of a single building, it is noted that these rules will result in the creation of a very large number of layers in a city wide model. Without

any technique to handle these, this would be impractical; therefore we include another network type, Pedestrian Combined Network (PCN). The intention of PCN is that a number of PCN submodels can be created at designer discretion, by merging PFN, PIN and PON.

Finally we have the Pedestrian All Network (PAN) to represent the entire network. This is identical to PCN except that it must be a complete system within itself, unlike a PCN which joins to other PCNs.

At a future date we intend to create automated tools to check that pedestrian networks conform to the rules outlined below. It will be helpful therefore if pilot data is generated to conform to these rules, to assist development of the checking tools.

4.3   Rules for PON - pedestrian outside network

PON must be supplied as

1.   one or more 3d polyline layers detailing links.
2.   one 3d point layer for each layer provided in (1), detailing dead ends and points at which the layer connects to other layers

Links in a PON must represent pedestrian paths. These include

1.   sidewalks
2.   edges of roads with no sidewalk, but where it is possible to walk (henceforth *informal sidewalks*)
3.   formal crossing points, such as pedestrian crossings, between sidewalks
4.   informal crossing points where sidewalks or informal sidewalks meet link ends in the road network (VTN)
5.   informal crossing points where sidewalks end
6.   pedestrian alleyways/paths not adjacent to roads

Links must contain a data field named PONTYPE which distinguishes between: formal sidewalks, informal sidewalks, formal crossing points (including type of formal crossing), informal crossing points, and other paths. This is in addition to the TYPE field specified in *Rules for all network layers* below.

A sensible starting point for PON would be a 2d network (with link end grade separations) draped over a terrain model. This must be converted to a 3d network, however if this approach is used it is preferable to supply the original 2d and terrain models in addition to the PON.

A PON must

1.   Contain no 2d intersections. Where links cross one another at different elevations, they must be broken at the point of crossing, creating a pseudonode.
2.   Adhere to the *Rules for all network layers* given below.

4.4   Rules for PIN - pedestrian inside network

PIN must be supplied as

1.   one or more 3d polyline layers detailing links. Links must contain a short integer data field named ELEVCHANGE which indicates whether or not the link changes in elevation along its length.
2.   one 3d point layer for each layer provided in (1), detailing dead ends and points at which the layer connects to other layers

Unlike a PON, 2d intersections are allowed in a PIN. To prevent introduction of errors that may not be caught due to relaxing this requirement, the ELEVCHANGE field is introduced. The intention of ELEVCHANGE is that the designer should explicitly mark all links which are intended to change in height. Thus ELEVCHANGE is information required from the designer and must not be set by automatic tools.

A PIN must

1. Have ELEVCHANGE field set manually by the designer, such that all links which change elevation at any point along their length have ELEVCHANGE=1, and all links which remain flat have ELEVCHANGE=0.
2. Adhere to the *Rules for all network layers* given below.

4.5   Rules for PFN - pedestrian floor network

PFN must be supplied as

1. one or more 3d polyline layers detailing links. Links must contain an integer data field named ELEVCHANGE which indicates whether or not the link changes in elevation along its length.
2. one 3d point layer for each layer provided in (1), detailing dead ends and points at which the layer connects to other layers

A PFN must

1. Contain no 2d intersections.
2. Be based around a fixed elevation E which is the elevation of that floor. All links with ELEVCHANGE=0 must have z=E at all points along their length. All links with ELEVCHANGE=1 must either start or end at z=E. Note this requirement means that each floor of a each building must be kept in a separate PFN layer.
3. Adhere to the *Rules for all network layers* given below.

A PFN is designed to allow easier editing of individual floors. As 2d intersections are not allowed, it is possible to draw complex floor plans more intuitively using PFN, and use an automated tool to break links at intersections.

4.5.1   PIN vs PFN for buildings

The question of whether to draw a building as PIN, or as PFN+PIN is left to designer discretion. For a simple building, the entire building model could be represented as a single PIN. If the designer wishes to model floors individually, they can create a PFN for each floor plus a PIN to connect the floors.

In this case, a decision must be made as to whether all PFNs are 'flat' – i.e. do they contain links which change elevation? Again this is left to designer discretion. If flat PFNs are used, the links between floors must be contained in a PIN, and one or more PFNs would be merged with this PIN to create another PIN representing the entire building. Alternatively the designer may choose to include inter-floor links in the PFN, in which case the entire building can be constructed by merging PFNs only to form the building-wide PIN.

4.6   PTN – Public Transport network

A PTN represents the public transport network, such as rail, and metropolitan and bus networks. It consists of links connecting points on the pedestrian network which would be connected by a journey on public transport. A dead end and connecting point layer is not necessary as it is assumed that all link endpoints fall on other pedestrian networks. PTN is supplied as a 3d polyline layer, however, it is not necessary to

encode the shape of links between alighting points, merely the presence of a link. 2d intersections are permitted and do not imply connectivity. They must adhere to *Rules for all network layers*.

4.7   VTN – vehicle transport network

The VTN represents the vehicle transport network – i.e. road centre lines. As with the PON it consists of a layer detailing links, and a layer detailing dead ends. The VTN is not linked to other layers so linking points are not required. VTN is supplied as a 3d polyline layer. 2d intersections are not permitted and do not imply connectivity. The VTN must adhere to *Rules for all network layers*.

4.8   PCN and PAN - Pedestrian Combined Network and Pedestrian All Network

A PCN (Pedestrian Combined Network) is the result of merging any combination of [PFN or PIN], PON and PTN. It obeys only the 'rules for all networks'.

A PAN (Pedestrian All Network) represents the complete system. It is the same as a PCN except that layer join markers are not permitted, as by definition the PAN should include all joined layers.

4.9   Rules for all network layers (excluding VTN)

All network layers must adhere to the following rules

1. It is encouraged to represent each link as a single polyline (no pseudonodes) except (1) where specified above (to signify e.g. loop links, or intersections in PON); (2) where different data must be attached to different sections of the link, e.g. escalators in the middle of a link.
2. Line layers must contain no dead ends, unless explicitly marked with a point in the corresponding dead end layer. Points where networks join to other networks (PON-PIN or PON-PON) must also be marked. The dead end layer must contain a short integer data field called JOIN, set as follows: 0 for a dead end, 1 for a join to another layer.
3. Line layers must contain no links which start and end at the same x,y coordinates. Where such links exist (either because the endpoints have different z coordinates, or because the links form an actual loop) a pseudonode must be inserted partway along the link to signify intent.
4. Line layers must contain no 3d intersections within a certain tolerance. The designer may choose this tolerance at their discretion. A recommended tolerance would be 0.5 metres, as paths cannot physically come closer than this without pedestrians colliding.
5. Line layers must indicate connectivity by endpoint coincidence, and only by endpoint coincidence. That is to say, lines are not considered connected unless they share an endpoint.
6. A tolerance shall be defined for the data set overall (at the designer's discretion but we recommend 0.01 metres). No link endpoints or dead end points shall fall within this tolerance of one another unless they fall on exactly the same point.
7. Line layers must contain a field called LINKTYPE to indicate the presence of special features such as escalators, elevators and pedestrian conveyor belts. In the case of escalators/conveyors which change height, the distinction must be made between UP and DOWN escalators.
8. One way links (e.g. subway network, or enforced one way systems) must contain a short integer field called ONEWAY, set as follows: 0 for bidirectional use, 1 for forwards traversal only, and 2 for backwards traversal only. Forwards and backwards refer to drawing order of points in the polyline representing the link. In the case of escalators/conveyors which change height, this field may be set to 0 as the LINKTYPE will specify direction. If ONEWAY is set to 1 or 2 on an escalator/conveyor then it must match the direction implied by LINKTYPE. In the case of conveyors which remain at a constant height, ONEWAY must be set to indicate directionality.

9. Elevators must contain a field CAPACITY to record capacity, either in person count or classifying small/medium/large.
10. Network layers should not confound angular analysis by introducing unnecessary turns (Fig. 2). When junctions fall within the tolerance of 3d intersection (rule 3 above), they shall be merged, and the link endpoints shall be made coincident.
11. All layer names should begin with the layer type: PFN, PIN, PON, PTN, PCN or PAN. Ideally this information would be stored elsewhere than the layer name; however we make this choice to maintain compatibility with shape files.

5   The linking file

A linking file must be provided to specify how all the different network components fit together. Plain text or .doc format is currently acceptable for this file.

If ArcGIS tools for model check and merge are to be created, the linking file could take the form of an ArcGIS modelbuilder model, which would then be automatically executable.

Where submodels have been merged to create a larger model, it is recommended to supply both the submodels and the larger model together as part of the network. The linking file must specify which models are the result of merging other models, and also whether they have been subject to further editing since merging.

6   Workflow

6.1   Choice of software

6.1.1   sDNA compatibility

Currently sDNA is a plug-in for ESRI – ArcGIS 10.x and Autodesk Autocad 201x including Autocad Map3D. sDNA+ which include 3D capacity is a plugin working with ESRI – ArcGIS 10.x only. The sDNA+ 3D workflow only differs from sDNA workflow in the creation of the 3D network. For a detailed overview of sDNA workflow see: How to use (Cooper, 2011), The friendly guide to sDNA outputs (Cooper & Chiaradia, 2011), Detailed measure descriptions (Chiaradia & Cooper, 2011), sDNA Network Format (Chiaradia & Cooper, 2011).

3D network are not processed by sDNA.

6.1.2   Editing with ESRI – ArcScene

The obvious choice for editing 3d shapefiles is ESRI ArcScene (part of the 3d analyst extension to ArcGIS). Unfortunately the current version of ArcScene contains a bug which inhibits feature snapping in 3d. ESRI are aware of the problem and are working on a fix (their reference NIM069520 "snapping fails for 3D features with extrusion"). However in the interim this renders Arcscene unsuitable for this work.

6.1.3   Editing 3D network with Autodesk Autocad Map3D (free to students and academics)

It is possible to create and edit shapefiles using Autocad map3d. As map3d contains sophisticated 3d editing and snapping features, we recommend this approach. Do **not** edit shapefiles as a map3d mapping layer, as this discards 3d information. Instead, shapefiles can be imported into map3d as Autocad objects, with data attached as object data, and preserving spatial reference. Models can be exported from Autocad objects to shapefiles in a similar way, though (1) it is necessary to manually specify export of all attached

object data, (2) it is necessary to select the 3d export driver to preserve height data, and (3) care must be taken to preserve the spatial referencing.

Map3d also includes Drawing Cleanup, a topology checking tool which can be used to fix intersection errors (this is useful for converting hand drawings into valid network models - see topology rules below).

6.2   Combined workflow for network creation

We propose the following workflow. Again this is subject to discussion and modification!

1. In ArcGIS, import VTN if desired for reference, and drape over terrain using ArcGIS 3d analyst.
2. Create/import PON and PTN and drape over terrain using ArcGIS 3d analyst.
3. Export PON/PTN as shapefiles, import into map3d (as separate layers).
4. Edit PON bridges/tunnels to attain correct three dimensional shape in map3d.
5. Backup map3d document containing PON and PTN.
6. For each building where an interior model is required
    o   Create PFNs and PIN in map3d, as separate layers. (Do not merge PFN to PIN – only create PFN where it is created directly).
    o   Encode object data (e.g. escalators, ELEVCHANGE) where required
    o   Export PFNs and PIN for that building, as separate shapefiles. Then remove from the map3d document.
7. Export corrected PON and PTN as separate shapefiles.
8. Load PON, PTN, PINs and PFNs into ArcGIS. Run automated model checking tools on them. Where errors are indicated, fix in ArcGIS or (if 3d editing is required) fix in Map3d and re-export.
9. In ArcGIS, for each building that uses PFNs:
    o   Merge PIN and PFNs to create PIN for entire building
    o   If errors are indicated, fix the source models generated in steps 2-6 (not the merged model generated in step 9.1) in ArcGIS or (if 3d editing is required) in Map3d and re-export, then re-merge.
    o   Save PIN for entire building.
10. In ArcGIS, for each area of the city (if there are more than one):
    o   Merge PON and PTN with all building PINs to make PCN. Do not use the same PON and PTN in multiple areas – if only one PON exists, either divide it for this task, or do not merge it at this stage.
    o   If errors are indicated, fix the source models generated in steps 2-6 (not the merged model generated in steps 9.1 and 10.1) in ArcGIS or (if 3d editing is required) in Map3d and re-export, then re-merge.
11. In ArcGIS, merge all PCNs (and PON/PTN if there is only one of each) to a single PAN. If errors are indicated, fix at source (steps 2-6) and re-merge.

At some point before analysis, it will be necessary to convert the models from shapefiles (.shp etc) to ArcGIS file geodatabases (.gdb). ArcGIS handles the latter more efficiently, so it may be faster to convert data to .gdb at an earlier stage.

6.3   Workflow for analysis

Once the 3d network is stored as a polyline class in 3d geodatabase format, it can be processed by sDNA+ Prepare and Integral. If cases exist where different parts of links contain different data (e.g. escalators) it may be better not to fix split links. The sDNA+ documentation is included with the sDNA+ installation. Particular attention should be paid to the hybrid metric functionality, which allows for assigning different

metrics to different links based on 3d and other attached data. This is described in detail in the *sDNA Advanced Config* document (along with the mechanism for handling one-way links such as escalators).
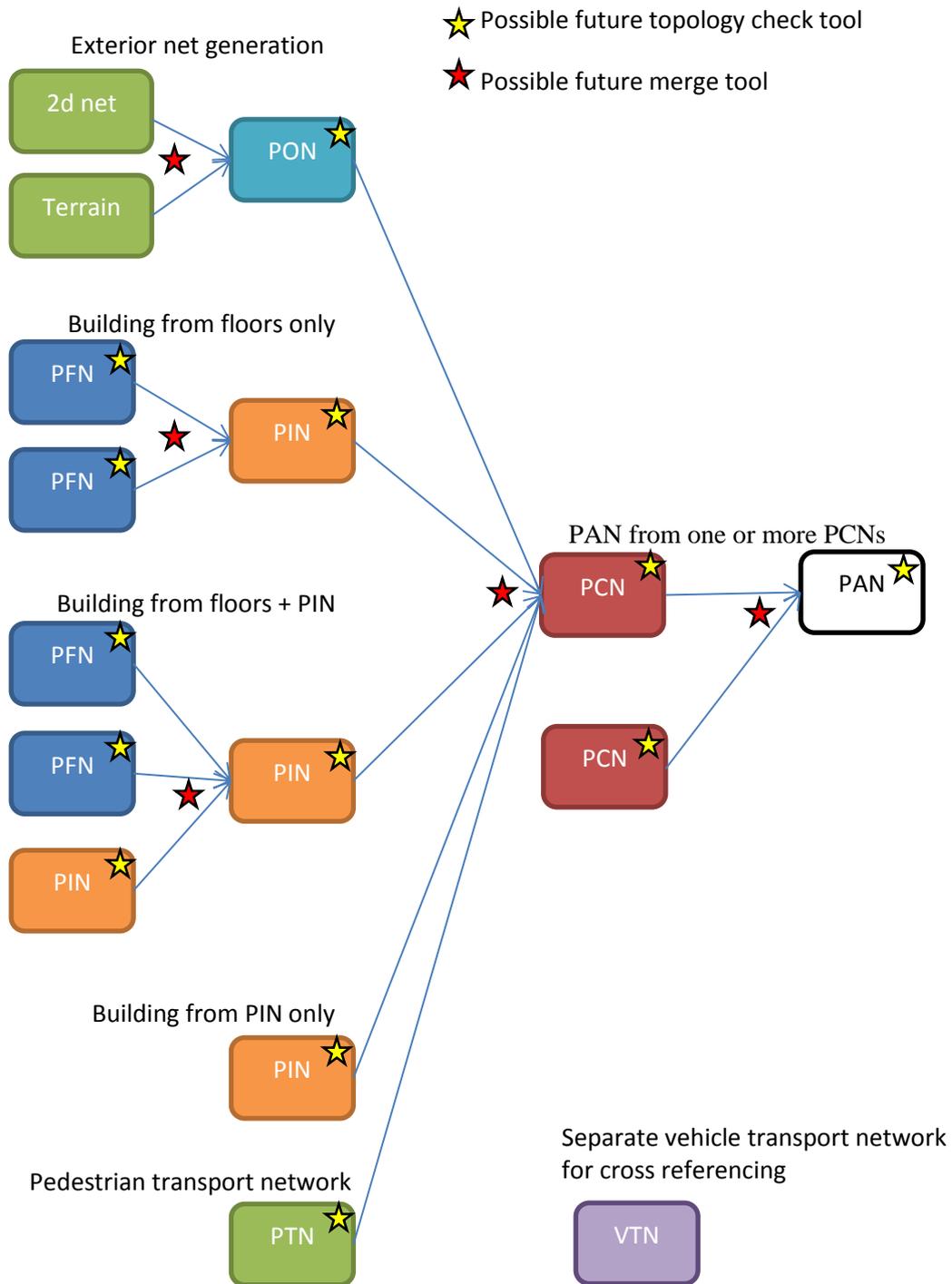

Figure 1 Illustration of workflow for constructing pedestrian combined network (PCN). Using topology verification at each stage to ensure model accuracy.
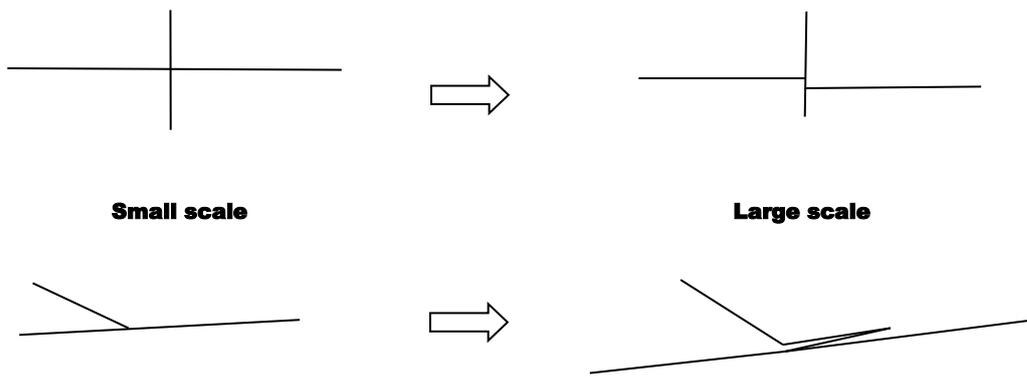
Figure 2. Illustration of junction encoding which breaks angular analysis
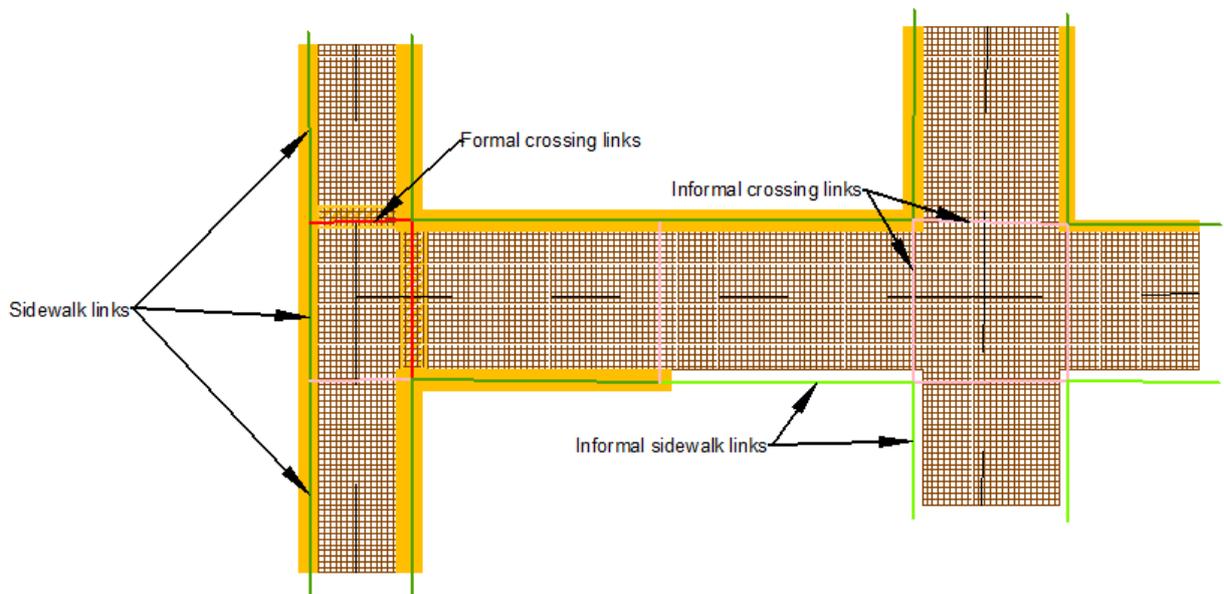

Figure 3. Illustration of formal and informal crossings and sidewalks

Table 1 Summary of topology rules for different layers in pedestrian network model

Topology Rule	PFN (floor)	PIN (inside)	PON (outside)	PTN (transport)	PCN (combined)	PAN (all)
No pseudonodes	encouraged, but not checked as there are exceptions					
Dead end or layer join marker on all dangles	✓	✓	✓	implied	✓	
Dead end marker on all dangles (no layer joins)						✓
No dead end or layer join markers except on dangles	✓	✓	✓	✓	✓	✓
No 2d (apparent) intersection (in plan view)	✓		✓*			
Elevchange marked on all links that change elevation	✓	✓				
All links start or end at floor elevation	✓					
No loop links (pseudonode instead)	✓	✓	✓	✓	✓	✓
No 3d intersection within human scale e.g. 0.5m	✓	✓	✓	✓	✓	✓
No endpoints closer than data tolerance e.g. 0.01m	✓	✓	✓	✓	✓	✓
Layer name begins with layer type	optional, but enabled by default					

* : in PON, apparent intersections are pseudonoded to denote intent

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