Perspectives in evaluating pedestrian facility within transit-oriented development context

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Abstract. Pedestrian facility is widely agreed an important component of transit-oriented development (TOD). The availability and quality of pedestrian facility relates to and affects other aspects of TOD. This article explores the role of pedestrian facility within TOD. This article is written through a literature review on the available body of knowledge regarding evaluation of pedestrian facility by using the concept of TOD as the base and framework for the literature review. It is found that the physical and perceived quality of the pedestrian facility are to be evaluated. It is found that there are some aspects to be evaluated network wide and some other aspects to be evaluated segment wide. Evaluated objects of the mentioned aspects can be analysed using various techniques and tools, including space syntax analysing using DepthMapX and other analysis using spatial analysis softwares. It is concluded that in order to comprehensively evaluate pedestrian facility within TOD context, various types of evaluation need to be carried out.

1. Introduction
It is commonly agreed that transit-oriented development (TOD) pays great concern on the activity of walking among the residents and subsequently pays great concern to the availability and quality of pedestrian facility within the developed area [1-5]. TOD promotes for the development of an area in which the residents walk, both in purposive and recreational manners. TOD promotes for the decrease in use of personal motorised vehicle and the increase in act of walking, along with the increase in act of cycling and use of transit, for the residents’ various kind of daily trips. Subsequently, TOD promotes for the development of sufficient and proper pedestrian facility in the area. Furthermore, TOD also promotes for the development of the built environment that encourage the residents to walk. A number of researches [4,6-9] mentioned some qualities that need to be owned by the pedestrian facility so that it can support, and even trigger, the residents to walk, that are safe, connected, active, vibrant, temperate and comfortable. In addition to that, some other researches [4,10] summarised some qualities that qualities that need to be owned by the pedestrian facility so that it can support the mode shift from using private motorised vehicle to taking transit among the residents.

The concept of TOD has been spreading worldwide, including to Indonesia as indicated by the recent stipulation of a number of planning laws that promote the application of TOD [6,11,12]. The laws provide for the development of areas applying TOD principles. However, there has not been any practical planning document guiding the evaluation of TOD or of the application of TOD principles. In line with that, there has not been any practical planning document guiding the evaluation of the
application of TOD principles regarding walking. Similarly, there has not been any document guiding the evaluation of the pedestrian facility within the developed area. This research intends to synthetize a comprehensive knowledge regarding the evaluation of pedestrian facility within TOD context that can be useful for the development of such practical planning document. Furthermore, this research intends to provide a way to better apply the TOD principles regarding walking and pedestrian facility.

2. Methods
This research was carried out under the intention of crafting a comprehensive and manageable way of evaluating pedestrian facility within TOD context. The availability of such way of evaluation is in turn intended to help better applying TOD principles regarding walking and pedestrian facility in the developed area. The research question is “What are the proper and feasible ways of evaluating pedestrian facility within TOD context?” This research is a descriptive and qualitative research. This research was carried out using a literature review on the available body of knowledge regarding evaluation of pedestrian facility. The TOD issues regarding walking and pedestrian facility mentioned in the previous section [1-6] serve as the base and boundary for the literature review. The source for the reviewed body of knowledge is research articles published within the last 10 years. Findings are grouped into the essentials of an evaluation, that are approaches, aspects and objects and data collection and analysis techniques and tools.

3. Results and discussion

3.1. Approaches: Evaluating the physical and perceived quality of pedestrian facility
When evaluating the quality of pedestrian facility, a number of researches [6,7,9,13-20] evaluated the physical quality of pedestrian facility. They evaluated the qualities that are intrinsic to the pedestrian facility, un-interfered by how the users of the pedestrian facility perceive the pedestrian facility. The evaluated aspects that are exclusive to this approach are the integration and connectivity of the pedestrian facility network. Space syntax analysis using DepthMapX software is commonly carried out for this approach. Figure 1 exemplifies an output of space syntax analysis using DepthMapX, that is a representation of a pedestrian facility network having segments of different connectivity level.

![Figure 1. A pedestrian facility network having segments of different connectivity level [21].](image)

More advanced analysis using spatial analysis softwares (e.g. QGIS, ArcGIS, etc.) are also common to be carried out. Meanwhile, a number of researches [22-25] evaluated the perceived quality of pedestrian facility. They evaluated the qualities that are experienced by the users of the various segments of pedestrian facility. Aspects that are commonly evaluated using this approach are the safety, security and comfort of the segments of pedestrian facility. Analysis of the data for the evaluation using this approach can be carried out without using any specific software.
The mentioned approaches are not self-sufficient or independent in evaluating pedestrian facility within transit-oriented development (TOD) context. Some aspects need to be evaluated using both approaches to be understood better. Tiwari [9], showed that while the perception of safety and security must be retrieved from the users of the pedestrian facility, the descriptors of the perceived safety of segments of the pedestrian facility can be found through space syntax analysis [9]. The descriptors of the perceived safety and security can be found through connectivity analysis of the pedestrian facility network. Similarly, some findings from one approach are not self-explanatory and need to be complemented by findings from other approach. Ozbil and Peponis [16] and Ozbil et al. [24] showed that the findings from connectivity analysis are not self-explanatory and can become explanatory when complemented by data regarding individual preference of walking distance and route. The findings from connectivity analysis can become explanatory when complemented by data regarding the distance users are willing to walk for.

An advanced evaluation of pedestrian facility combining both approaches has recently been developed and tried [20]. Physical qualities of pedestrian facility are gathered in the form of street-view images (SVIs) and processed using SegNet. The processed SVIs are then analysed by machine learning previously set emulating users’ preference. The research produced machines’ outcome of perceptive assessment of pedestrian facility complemented by the physical qualities of the pedestrian facility that construct the outcome. The machines’ outcome has been tested and found in line with the ones from (human) panel of experts. Figure 2 illustrates the SegNet processing of street-view images into color-coded images that will be analysed by machine learning.

**Figure 2.** An illustration of SegNet processing of street-view images into color-coded images [20].

3.2. Aspects and objects: Evaluating the qualities of the network and the segments of the pedestrian facility

In regards for the pedestrian facility network, integration and connectivity are two aspects that are commonly evaluated [6,7,14-16,18,19]. Integration refers to the relative distance of each segment to other segments of the pedestrian facility network. Connectivity refers to the number of connections, both direct and indirect, each segment has within the pedestrian facility network. For both aspects, the object being evaluated is the lines representing segments of pedestrian facility within the network [14,15].

In regards for the segments of the pedestrian facility, safety, security and comfort are three aspects that are commonly evaluated [8,9,13,22-25]. Safety specifically refers to the ability of the segment preventing the users experiencing physical injury when interacting with other road users. Security refers to the ability of the segment preventing the users experiencing any unintended accidents (e.g. pickpocketing, sexual harassment, etc.). Comfort refers to the general ability of the segment making wide range of pedestrians use the segment without significant hassle at any time and condition. For these aspects, the object being evaluated includes the sidewalk width, barrier, lighting, greenery and shade, signage, building frontage and crossing and refuge.

Some aspects are able to be evaluated network-wide and segment-wide. For instance, safety and security of each segments of pedestrian facility can be described by the segment’s integration and connection to other segments. Security of every segments within the evaluated area can also be described by the composition and orientation of land parcels within the evaluated area.
3.3. Data collection and analysis techniques and tools

Analysis of pedestrian facility network using space syntax analysis with DepthMapX software requires a base map of the network with each segment of the pedestrian facility represented as a line. The base map can only contain the lines and no additional data can be attributed to the lines. The base map can be produced manually or converted semi-automatically from any visual map. Space syntax analysis with DepthMapX can only analyse the depth/distance between each line in the base map [26]. Advanced analysis of pedestrian facility network using a more feature-packed spatial analysis software (i.e. QGIS, ArcGIS, etc.) requires at least a base map of the network with each segment of pedestrian facility represented as a line. The base map can be enhanced in many ways. Additional data (i.e. line width, line usage, etc.) can be attributed to the lines. Additional component with various attributes (i.e. land parcel with various usage, land parcel with various building height, etc.) can be added complementing the pedestrian facility network base map. The mentioned spatial analysis softwares can carry out analysis of various things, such as pedestrian flow, pedestrian travel distance prediction, etc. [27,28].

Analysis of segments of pedestrian facility commonly includes data collection through physical observation. Physical observation is commonly carried out manually (using human eyes) [13,24,25]. Figure 3 exemplifies a graphical summary of a road space, including the pedestrian path, in which the components are observed and recorded manually. Machine-assisted physical observation is still being developed [20] and may become the norm in the future due to its ability to record and process a massive amount of built environment data in short time frame. Analysis of the perceived quality of segments of pedestrian facility always include data collection from the users in the form of interview, both direct and indirect interview. Data regarding the segments of pedestrian facility, including both the physical and perceived quality of the segments, can be added to the base map that will be analysed using the previously mentioned spatial analysis softwares [27,28].

![Figure 3](image-url)

**Figure 3.** A graphical summary of a road space observed and recorded manually [13].

4. Conclusion

The last section has presented that a range of perspectives is available for properly evaluating pedestrian facility within transit-oriented development (TOD) context. A range of perspectives is available for evaluating pedestrian facility’s ability to trigger the residents to walk and to support the residents to mode shift to taking transit. We may conclude that in order to comprehensively evaluate pedestrian facility within TOD context, various types of evaluation need to be carried out. Various aspects of the pedestrian facility need to be evaluated, in which for each aspect a number of objects need to be evaluated with various approaches. Data of each object need to be collected and analysed using various techniques and tools. Table 1 presents an example of a comprehensive evaluation design. The table presents data collection and analysis techniques and tools that are considered feasible at the moment. Advanced techniques and tools, such as big data (e.g. Google users’ trip data) and the one used in Zhang et al. [20], are not listed considering that they have not been commonly used. Furthermore, before such comprehensive evaluation being carried out, the scoring and benchmarking system need to be set beforehand.
Table 1. Example of an evaluation design of pedestrian facility within TOD context.

| Aspect                     | Object                                      | Approach | Data collection technique and tool                                      | Data analysis technique and tool                                      |
|----------------------------|---------------------------------------------|----------|------------------------------------------------------------------------|------------------------------------------------------------------------|
| Integration and connectivity | Lines (segments) of the network              | Physical | Pedestrian network base map acquisition/creation                       | Space syntax analysis using DepthMapX; spatial analysis using QGIS     |
|                            | Distance travelled                           | Perceptive| Indirect interview using questionnaire                                | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |
| Safety                     | Lines (segments) of the network              | Physical | Pedestrian network base map acquisition/creation                       | Space syntax analysis using DepthMapX; spatial analysis using QGIS     |
|                            | Barrier between road and sidewalk           | Physical | Physical observation                                                   | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |
|                            | Crossing and refuge                         | Physical | Physical observation                                                   | Simple Statistical analysis using Ms. Excel; spatial analysis using QGIS|
|                            | General opinion; specific opinion regarding objects of physical evaluation | Perceptive| Indirect interview using questionnaire                                | Simple Statistical analysis using Ms. Excel; spatial analysis using QGIS|
| Security                   | Lines (segments) of the network              | Physical | Pedestrian network base map acquisition/creation                       | Space syntax analysis using DepthMapX; spatial analysis using QGIS     |
|                            | Lighting                                    | Physical | Physical observation                                                   | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |
|                            | Building frontage                           | Physical | Physical observation; land parcel base map acquisition/creation       | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |
|                            | General opinion; specific opinion regarding objects of physical evaluation | Perceptive| Indirect interview using questionnaire                                | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |
| Comfort                    | Sidewalk width                              | Physical | Physical observation                                                   | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |
|                            | Greenery and shade                          | Physical | Physical observation                                                   | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |
|                            | Signage                                     | Physical | Physical observation                                                   | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |
|                            | General opinion; specific opinion regarding objects of physical evaluation | Perceptive| Indirect interview using questionnaire                                | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |
| Controller                 | Opinion regarding pedestrian facility's attractiveness to be used for walking | Perceptive| Indirect interview using questionnaire                                | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |
|                            | Opinion regarding pedestrian facility's ability to trigger mode shift | Perceptive| Indirect interview using questionnaire                                | Statistical analysis using Ms. Excel; spatial analysis using QGIS      |

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