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Using space syntax to assess accessibility of multimodal urban hubs and seamless mobility within the hubs

Case study Delft-Campus train station

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ABSTRACT

Multimodal hubs connect different modes, allowing people to switch from one mode to another and seamlessly access/egress to/from their origin/destinations. However, there are limited methods to estimate the impact of future measures on the accessibility of multimodal hubs. These future measures could be wide reaching, among others, introduction of different schemes in the planning of the hub or introduction of new modes at multimodal hubs. This study provides interdisciplinary cross-cutting method including transport and urbanism literatures, by using Space Syntax method. This method allows the transport planners to analyse and compare the current situation and the proposed development plan. In this research, we show how changes made in urban spatial configuration can impact the accessibility of intermodal hubs.

To learn about the impacts of the spatial configuration of a city on station design, we performed a case study at Delft Campus train station in the Netherlands, which is under construction to become a multimodal hub. Firstly, we analyse the current situation and then the proposed development plan in terms of, integration, choice, accessibility and intelligibility, using segment analyses. Furthermore, the immediate surrounding areas of the station have been analysed by Visual Graphic Analysis to find visual accessibility within the hub. Although the municipality proposed plans claim that the station's accessibility would be enhanced, our method indicate otherwise and the proposed changes are not highly effective in increasing accessibility.

Finally, some design recommendations for multimodal hubs are proposed. This study is a prerequisite for designing the multimodal hubs considering emerging modes.

KEYWORDS

Accessibility, multimodal hubs, space syntax, segment, VGA

1 INTRODUCTION

An accessible transit system and a station can be interpreted as how easily people reach their destinations (Noichan & Dewancker, 2018) and how easily people switch seamlessly between different modes of transportation (Guo & Wilson, 2007), including walking, cycling, public, and private respectively. Emerging access/ egress modes improve public transport systems and may persuade more people to shift from private to PT, leading to more liveable and sustainable cities (Van Kuijk et al., 2021, Torabi et al., 2022). A multimodal hub mainly refers to a train/tram station, offers multiple modes to switch seamlessly for different users and different travel purposes (Henry and Marsh, 2008), and provides an integrated and sustainable mobility network (Venhoeven, 2012). The integration analysis of an urban street network determines the location of vital urban centres (van Nes & Yamu, 2021). Thus, the multimodal hub should be located in the most accessible area for different transport modes.

Due to the growth of the population and mobility demands, short-distance mobility in cities are highly valued (Pandit and Knoll, 2019). Spatial structure directs people's movement, either by foot, public transport, bicycle, or car, and it affects the distribution of functions in the cities (van Nes and Yamu, 2021). In addition, spatial configurations can promote walking, cycling, and the use of public transport in the cities (Yamu et al., 2021). Van Nes and Yamu (2021) stated that the lack of available and efficient public transport modes besides the unsuitable spatial structure of the mobility network negatively affect the use of sustainable transport modes, increasing the use of private cars. The location of the station in the street network and accessibility of stations to their surroundings make the public transport accessible (van Nes and Yamu, 2021). The highly integrated routes have a high potential for locating transport stations (van Nes and Yamu, 2021). In general, there is a lack of a comprehensive understanding of the relation of public transport hubs with their surrounding areas and the whole city and these spatial relations are not taken into account (van Nes and Yamu, 2021).

In general, the municipality proposed development plans for stations aim to increase the accessibility of the stations in the cities in order to encourage people using public transport versus private cars. However, these proposed plans are not implemented yet to be analysed empirically to determine how these plans succeed. There is a need for an analytical method to predict spatial configurative changes in detailed. Thus, before arriving the emerging access/egress modes, the proposed development plans should be investigated.

The multimodal hub of the future will only be a success if all modes and passenger preferences and behaviour are investigated integrally, resulting in an integrated design. This research will investigate the accessibility of the station in the city, focusing on the existing spatial conditions and examining how the proposed development plan increases/decreases the station accessibility physically and visually. So this research project aims to provide information about the impact of spatial configuration on the accessibility of hubs and seamless mobility within hubs, which are necessary to design multimodal hubs considering emerging access/egress modes. To do this, the multimodal hubs initially should be spatially analysed in terms of physical and visual accessibility in the city and station area.

This study uses the Delft-Campus railway station in Delft, a bicycle-friendly city in the West of the Netherlands, as a case of an emerging small multimodal hub. To determine accessibility of multimodal hubs, space syntax method has been performed. The space syntax method enables analysing and quantifying the accessibility and wayfinding of any space (Yamu & van Nes 2017), which are consistent (van Nes and Yamu, 2021). Furthermore, space syntax models propose a quick and straightforward way that provides the opportunity to test different design proposals (Uyar et al., 2017). Although space syntax has a long history, this method is usually used in pedestrian behavioural studies and is rarely used to study other transport modes (Cutini, 2016; Paul, 2011, 2012; Rybarczyk and Wu, 2014), which is considered in this research. In addition, to the knowledge of the author, therein is no scientific literature for the use of space syntax on designing the total station's area finding out spaces for emerging modes. This study employed measures of this method and objectively analysed accessibility of Delft Campus station, strengths and weaknesses of the current and the municipality proposed development plan for the station within the city in DepthmapX software environment. The outcomes will be used to provideimprovement design recommendations.

The paper will outline the methodology in the second section. The spatial analysis regarding the current plan and the municipality proposed development plan and their comparison are discussed in the third section. Moreover, the conclusions and the discussion will be presented in the fourth section. And some recommendations will be provided in the last section.

2 METHODOLOGY

2.1 Aim of the research and the approach

This research project aims to provide the impacts of spatial configuration on the accessibility of hubs and seamless mobility within hubs, which are necessary to design multimodal hubs considering emerging access/egress modes. To do this, the multimodal hubs initially should be spatially analysed in terms of physical and visual accessibility in the city and station area. Since space syntax utilises graph theory and analyses and quantifies the accessibility and wayfinding of any spaces (Yamu & van Nes 2017), this study employed measures of this method and objectively analysed multimodal hubs areas. Figure 1 shows the approach of this research. The first step involved the current train station's accessibility within the city and using space syntax to measure the street network. The segment-based analysis is utilised in this research because its indicators can better explain pedestrian behaviour movement than axial map-based indicators (Sharmin and Kamruzzaman, 2018). Using segment analysis, the least angle change (geometric) and fewest turns (topological) weightings to relations between each segment and others. We applied them at the city scale from each segment. Secondly, the city will be re-examined according to the proposed development plan of the municipality. To find the advantages and disadvantages of the proposed plan, the current and the proposed plan will be compared. Thirdly, the immediate surroundings of the station, considering the proposed plan, will be analysed by VGA. Finally, based on the outcomes, different design recommendations will be proposed to improve the accessibility of the station in the city and seamless mobility within the station surrounding area.

Since the Delft-Campus station is under construction, the final plan is not publicly exited. So for this research, Google Map, site observation, 3D pictures of BenthemCrouwel office, and the municipality report, which is available on the Internet, have been used.

2.2 Space Syntax method

Space syntax, which Bill Hillier proposed in the 1970s, emerges as a set of theories and methods that studies the correlation between spatial configuration and human movement. Space syntax looks at spaces by focusing on the organisation of spaces, movement patterns and their social meanings (Dursun, 2007), has been used primarily in the fields of urban design and architecture (Koohsari et al. 2016). Many spatial analyses and software development have been improved (van der Hoeven & van Nes 2014).

Space syntax can be applied at different scales, from very local such as arranging furniture in a office to increase collaborative interactions to regional scale such as understanding different centralities in urban regions (van Nes & Yamu, 2021, p.7). The space syntax is used to assess the interior spatial structure of complex buildings such as railway stations and subways (van der Hoeven & van Nes 2014) and external spatial structures such as plazas (Bendjedidi et al., 2018)—however, to the knowledge of the author, therein is no scientific literature for the use of space syntax on designing the total station's area finding out spaces for emerging modes. The method can also compare the spatial changes resulting from urban restructuring (van Nes & Yamu, 2021, p.7) considering development plans. Thus, this method supports the design and planning of urban spaces (van Nes & Yamu, 2021).

Although it does not mean that this method necessarily reveals the best design's answer to spatial challenges, it can predict socio-economic impacts of urban planning and design proposals (van

Nes & Yamu, 2021). As a result, this method can analyse the spatial configurative changes in detailed considering the design proposal (Yamu et al. 2021).

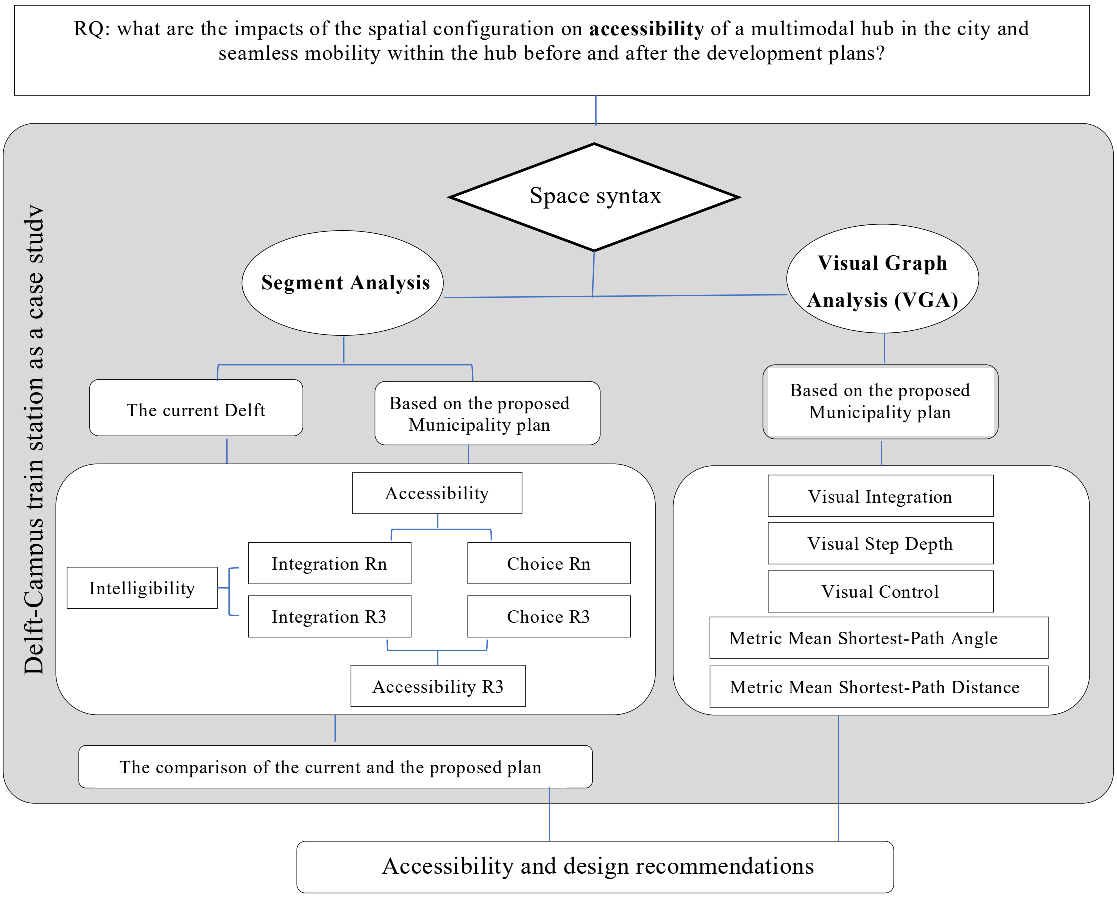

Figure 1. The diagram shows the project approach via Space Syntax Method.

Space syntax is based on three concepts: the axial line, the convex space, and the isovist field. The axial map represents the connections of each space to all other spaces drawn by linked axial lines (Hillier and Hanson 1984; Jeong et al., 2015), transformed into an axial graph, which is suitable for computation as well as a quantitative analysis of spatial layouts (Noichan and Dewancker, 2018). In order to improve computational angular analysis of streets with various local radii, the axial map is broken into a segment map, and segment length is considered in the calculation (Hillier, 2001; Yamu, van Nes, and Garau 2021). By splitting the axial lines at intersections into segments, a segment map analysis provides the derivation of angular distance (sum of angles) from A to B (Hillier and Iida, 2005; Turner, 2001, 2007; Shatu, Yigitcanlar, and Bunke, 2019). Moreover, it considers the minor variations in directional changes (Shatu, Yigitcanlar, and Bunke 2019).

Space syntax can quantify accessibility using different measures considering integration/mean depth and choice/betweenness. Note that these measures are derived as both global and local measures (Shatu, Yigitcanlar, and Bunke, 2019). In the other word, space syntax measures to-movement (closeness or accessibility of spaces from all others called integration) (Hillier & Iida, 2005; Cutini, 2010) and through-movement (betweenness or how likely is a space to be chosen as part of a route between spaces called choice) (Cutini, 2010; Hillier, 2016), potentials of every public street segment concerning all other street segments (Hillier, Yang, and Turner 2012).

2.2.1 Segment Analysis

This research considers the current map and the proposed development plan of Delft municipality and accounts for four parameters through a transition, from a micro- to macro-based perspective, involving all modes of travel.

To understand Delft accessibility and spatial configuration, segment (angular and topological) analysis is evaluated. The measures include *integration* (global and R3), *choice* (global and R3), *intelligibility* and *accessibility*. Generally speaking, 5-15 minutes (400-1200 meters) is the average walking distance between the *station* and destination that people are comfortable passing (O'Sullivan et al., 1996, Olszewski et al., 2005). In addition, the catchment distance for station neighbourhood can be defined by metric step depth in Depthmap as a feasible method for spatial analysis (Chen and Karimi, 2019). Metric step depth follows the shortest path from the station to all other segments (streets) within the street network, and the path length is calculated in meters (Turner, 2004). In our study, besides the global assessment, the parameters have been evaluated within radius1 km, based on the comfortable walking timeframe for people and metric Step Depth.

- ***Integration***

  Integration/mean depth, refers to the average number of directional changes required to access a line in an urban system from all other lines in that network (Hillier & Hanson 1984, Chen et al., 2015; Edgü et al., 2015; Kiliç-Çalğici et al., 2013; Lerman et al., 2014).

- ***Choice***

  Choice/betweenness refers to the ratio of the shortest paths through a line over the total number of all shortest paths in that map (Volchenkov and Blanchard, 2008).

- ***Intelligibility***

  Intelligibility is a property that is based on the correlation of global Integration (Rn) and local Integration (R3) (Penn, 2020). A robust positive correlation specifies the high intelligibility of the area how easily the spaces are navigable (Pandit & Knol, 2019). One of the characteristics of critical urban centres such as stations is permeability and accessibility. It can be interpreted that the intelligibility of a station should be higher than the intelligibility of the whole city.

- ***Accessibility***

  Accessibility refers to the correlation between integration and choice value (Asami et al., 2001; Hillier, 2001; Park, 2009; Legeby, 2013; Al Sayed et al., 2014; Topçu, 2019).

2.2.2 Visual Graph Analysis (VGA)

An isovist field represents the panoptic view of a person from a given point in the built environment (Benedikt, 1979; van Hoeven & van Nes 2014). It is a field of vision (Batty, 2001) used for wayfinding and orientation in an urban area (van Hoeven & van Nes 2014). The sum of isovist fields for a public space is called the isovist map (Yamu, van Nes, and Garau 2021). Recently, one-point and all-points isovist can be analysed by Visual Graph Analysis (VGA) method using Depthmap software, an open-source application developed by University College London (van Hoeven & van Nes 2014; Yamu, van Nes, and Garau 2021). According to the mentioned concepts, the primary assumption is that people have linear movement interaction in convex spaces, and their panoptical views are changed when moving through a built environment (van Hoeven & van Nes 2014). This assumption can be used to analyse and design multimodal hubs. The VGA considers spatial configuration of the built environment at eye level (what people can see) and at-knee level (where people can move) (Turner et al. 2001).

- ***Visual Integration [HH]***

  Visual integration (the universal visual distance) explains the number of needed visual steps to link all points to others within the system.

- ***Visual Step Depth***

  Visual step depth is the least amount of visual steps (cell) required to reach another point in that space (Koutsolampros et al., 2019). It is a measure that calculates the distance in terms of visual steps instead of metric distance (Berghauser Pont et al., 2017).

- ***Visual Control***

  Visual control is defined "as the area of the current neighbourhood concerning the total area of the immediately adjoining neighbourhood" (Turner, 2004). It means that since a large number of spaces can be seen from an area, it has a high visual control (Turner, 2004).

- ***Metric Mean Shortest-Path Angle***

  The shortest path angle means the path with the minor angular deviation (the straightest route) through the system (Hillier and Iida 2005, p. 475). Metric Mean Shortest Path Angle is referred to the average accumulated angular deviation encountered on each of the shortest paths (Koutsolampros et al., 2019).

- ***Metric Mean Shortest-Path Distance***

  The metric distance calculates the shortest distance from everywhere to everywhere else. Metric Mean Shortest Path Distance is referred to the average metric distance required (Koutsolampros et al., 2019) to reach every cell in the set through the shortest metric path.

DepthMap, a unique software developed by UCL's Space Syntax Laboratory, calculates the syntactic, morphological variables of the spatial system and automatically colours each space based on the size of the syntactic variables of each axis in a range from red (most integrated) to blue (most segregated) (Li et al., 2017). This software can calculate the topological distance (the lowest number of direction changes from each street segment to all others), the geometrical distance (the lowest number of angular deviations from each street segment to all others) as well as the metrical distance (the shortest distance from a street segment to all others) within a built environment (Hillier et al., 2007). In addition, the software can consider the radius in three terms; 1) Topological radius (a set number of direction changes from each street segment to all others, 2) Geometric radius (a given number of angular deviations (in degrees) from each street segment to all others), and 3) Metric radius (a given number of metric distances (in meters) from each street segment to all others (Turner, 2008).

Although space syntax has a long history, this method is usually used in pedestrian behavioural studies and is rarely used to study other transport modes (Cutini, 2016; Paul, 2011, 2012; Rybarczyk and Wu, 2014), which is considered in this research. In addition, this method enables analysing and quantifying the accessibility and wayfinding of stations and testing different design proposals (Uyar et al., 2017). Thus, it has been selected for this research to study the impacts of the spatial configuration of a city on accessibility of an urban multimodal hub and seamless mobility within the hub before and after the development plans.

2.3 Delft-Campus train station as a Case study

Scheltes (2015) and Torabi et al. (2022) studied the modal split of the access/egress trips for the coming years in some case studies in the Netherlands and found that almost half of people are interested in new, emerging, and future modes. This study evaluates how emerging modes affect the modal choice of travellers in a multimodal hub which helps to predict access/egress mode choice decisions at stations.

Currently, up to 17% of the trips are considered multimodal trips, using at least two different transport modes for medium-distance transferring (20-40 km), more than half of them (61%) are covered by train as the principal transport means (Kennisinstituut Voor Mobiliteitsbeleid, 2014)between urban areas in the Netherlands (Van Nes et al., 2014). For this reason, the role of railway stations as transit nodes is crucial and well investigated by several researchers (see, for example, Molin & Timmermans, 2010; Puello & Geurs, 2015; Shelat et al., 2018; Van Mil et al., 2020 and Yap et al., 2016).

The city of Delft is a small-medium sized city with around 103,500 inhabitants, located in the province of South Holland in The Netherlands. Nowadays, the city is connected with the rest of the country via the A13 and A4 highways, running parallel to the Schie (a canal connecting Rotterdam with Leiden), as well as two train stations (Delft and Delft-Campus), and two tram lines.

Delft is well accessible by public transportation and scores favourably with above-average growth in train passengers as the top 20 stations in the Netherlands. Due to the high-quality cycling infrastructure, bicycle makes up more than 50% of all movements in the city.
The city is highly north-south divided by the Kruithuisweg highway and east-west divided by railroad and Schie canal. The north (well-functioning side), the south (dis-functional side), the west (the most residential) and the east (almost all companies and institutions) are connected only via some bridges and overpasses. It can be concluded that working and living are not well integrated into the city.

Delft-Campus train station, which ProRail introduces as a so-called 'Basic station[1]' with around 5000 passengers per working day (Spoorbouwmeester, 2012), is one of the two train connections to Delft and the central train station for Delft University of Technology (TU Delft). It has connections only to bicycles, car parks, and no public transport modes except shared bicycles and shared scooters. Although accessibility in the city is good, it is rather low in the Delft campus station area and the Schieoevers area. Due to the lack of urban functions in the Schieoevers area (existing industrial buildings and the (vacant) office buildings), it could be argued that there is a "functional gap" between the east and the west side of the city (Van der Steeg, 2016). Thus, the Delft-Campus station is not integrated into the urban morphology of the immediate surrounding area (fig. 2)

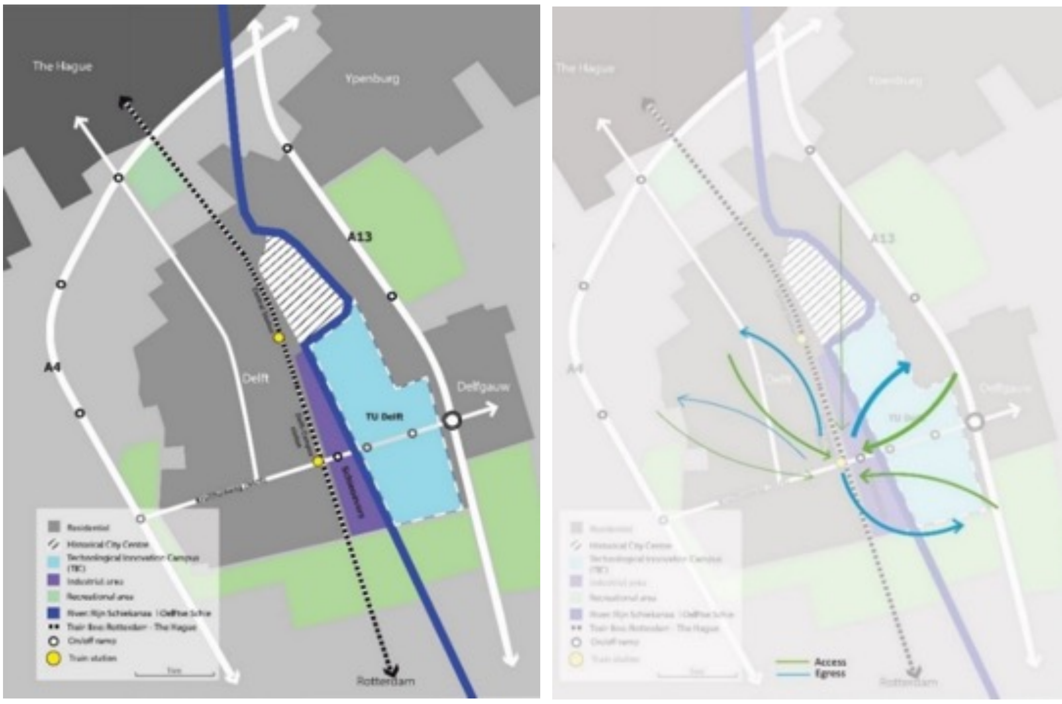

Figure 2. The left map shows Delft morphology, accessibility and barriers. The right map shows the passengers accessing/egressing to and from Delft Campus station.

Delft Mobility Program 2040 and Environmental vision Delft 2040, the reports of Delft municipality, aim to improve accessibility and increase sustainability in Delft (Delft Gemeente,

[1] ProRail named stations with 1000-10,000 passengers per day as 'basis station' in The Netherlands (Spoorbouwmeester, 2012).

2021 a,b). Delft will continue to develop in the coming decades, and the municipality has the ambition to add 15,000 homes and 10,000 jobs in 2040. This city growth by about 30% by 2040 will negatively affect the accessibility and mobility of Delft if suitable measures are not taken (fig. 3).

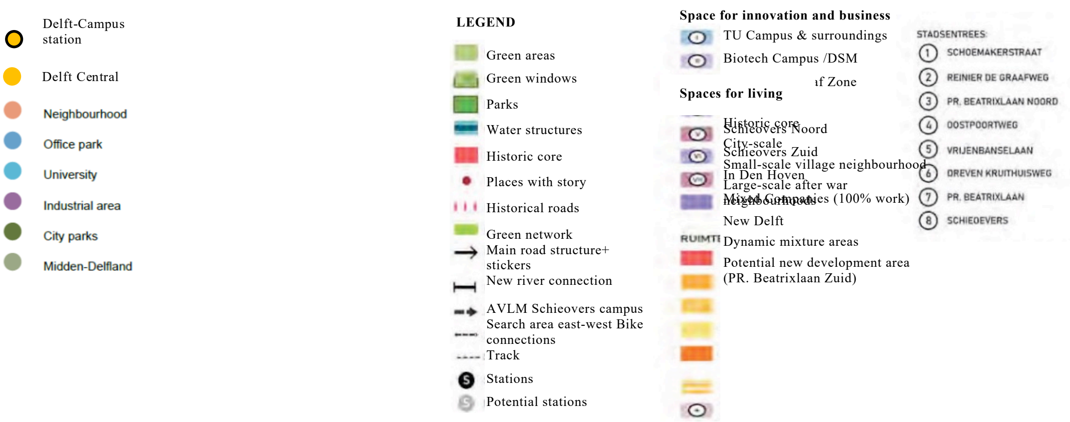

Figure 3. Delft current map (left), and the proposed plan of Delft municipality for 2040 (right).

Innovations offer opportunities that accelerate the mobility transition from private cars to more public transport modes. Shared mobility can provide sufficient accessibility and contribute to a sufficient quality of life in the area. By developing the station based on emerging modes and transforming Schieoevers into a metropolitan area with a mix of working, living and services, and due to the proximity of the station to the University and the science park, the Delft-Campus train station can perform as an essential multimodal hub that is considered the case study in this research. Figure 4 compares the Delft-Campus station before some recent constructions to the proposed station for 2040, presenting some current pictures and some 3D models.

3 SPATIAL ANALYSIS

To achieve the impacts of the spatial configuration of a city on accessibility of an urban multimodal hub and seamless mobility within the hub before and after the development plans, this spatial analytical framework is divided into physical accessibility analysis (segment analysis) and visual accessibility, Visual Graphic Analysis (VGA).

Up: Recent Delft-Campus before the tunnel and some other new constructions (google maps), Bottom: proposed Delft-Campus 2040 (3D pictures; ref. https://www.benthemcrouwel.com).

North-south access to the station (Macellus Emantspad) and the empty area mentioned later as area C

Accessing from the east to the west of the station through the new tunnel under the rail.

The east side of the station divided by the tunnel (mentioned later as are A, B)

Figure 4. The comparison of the current and the proposed Delft-Campus train station area.

3.1 Evaluation of physical accessibility and intelligibility of the station before and after the municipality proposed plan

The parameters and their perspective concerning accessibility are discussed in the following section. Figure 5 (a,b) shows the local and global integration of Delft in the current situation and based on the proposed municipality plan, respectively. The maps presented that the current local and global accessibility are relatively low. The proposed plan aims to promote a strong network with low-speed access to the Delft-Campus station. So, the proposed plan tried to improve the integration by adding new connections within the city.

In general, the results of global integration show that although Delft Campus station is located on one of the most integrated roads in the city, it is not located at the most integrated intersections (shown with circles in fig. 5b). The peripheral area of the station has a low integration due to some reasons; the large industrial blocks (caused low connections from north to south and east to west), the presence of canals in the west of the station, and the railroad itself.

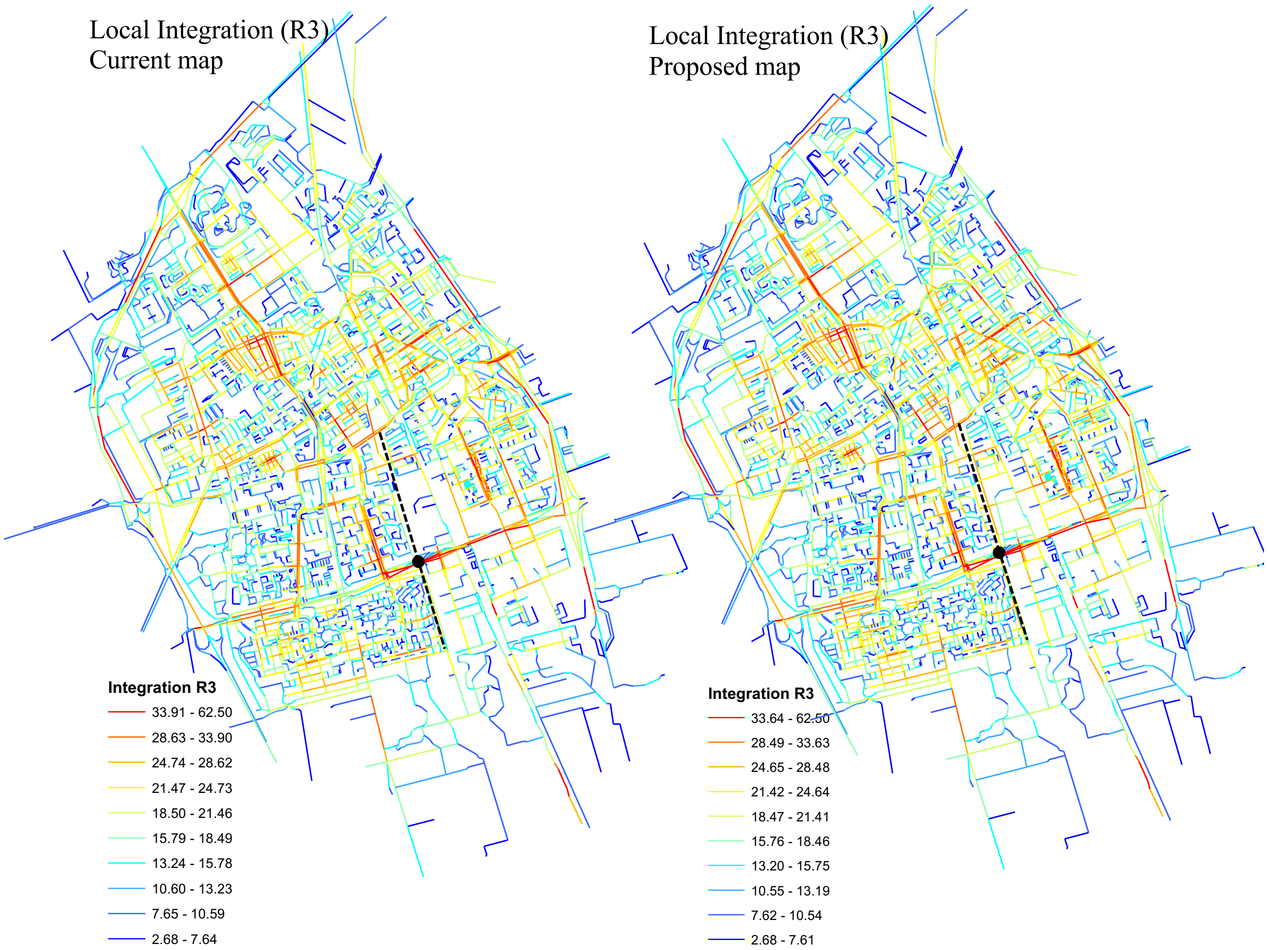

Figure 5a. Segment Map of Delft; Local integration , the current and the proposed plan.

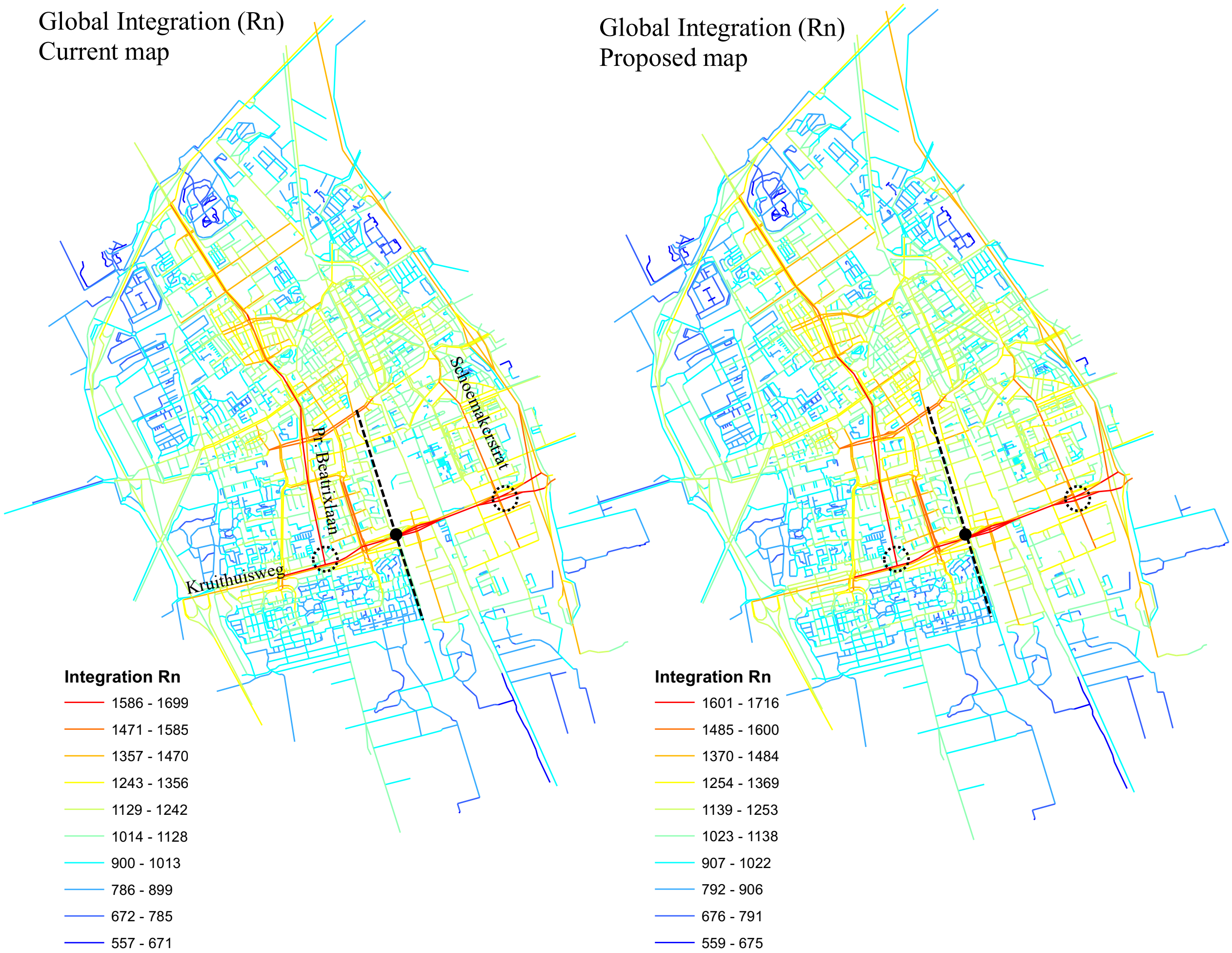

Figure 5b. Segment Map of Delft global integration, the current and the proposed plan.

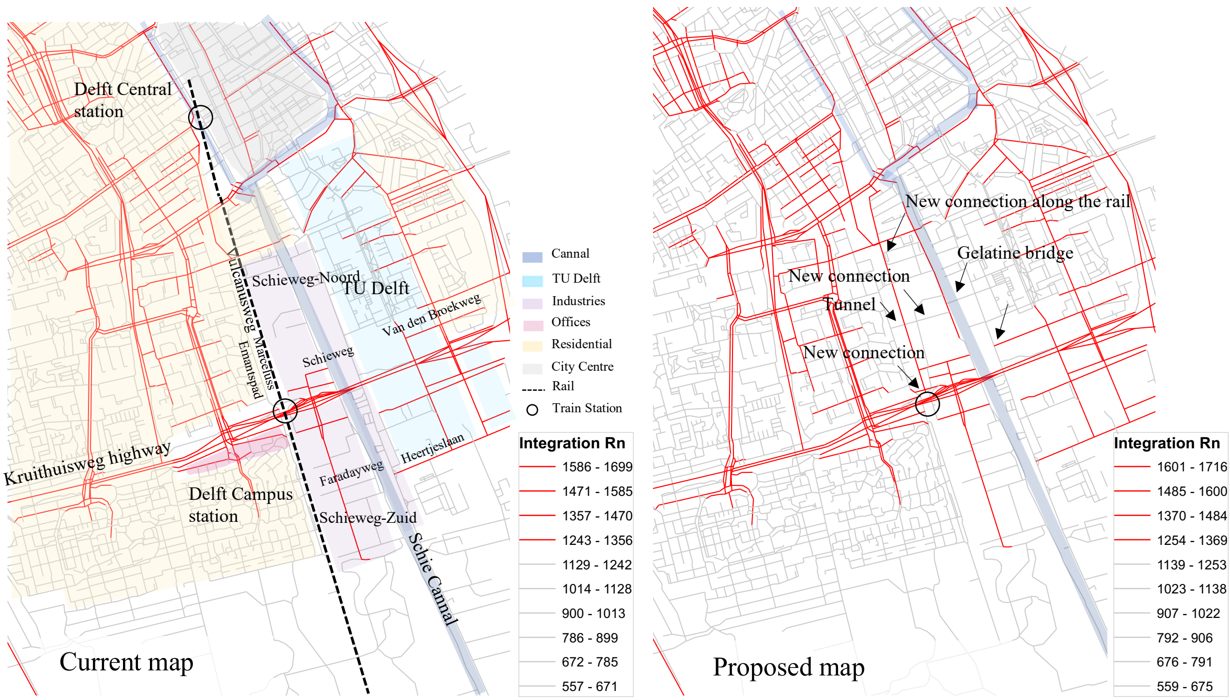

Figure 6. Global Integration of Delft City (segment map), the current and the proposed plan, presenting essential functions, stations, and the new connections in the proposed plan.

With the implementation of the new plan and the increase of connections, global and local integration will be increased in the city (Fig. 6). The higher local integration values than the global present a better perspective of short-distance mobility and pedestrian movements. The rise of east-west connections (besides roads, the Gelatine bridge and two tunnels under the railroad; one near the station and the other is in the north of the station) has caused the reinforcement of integration of the parallel axes of the rail line, which also indicates the strengthening of the central structure of the city. Before implementing the proposed plan, the western part of the city was well-integrated compared to the east, though, by increasing the west-east connections of the canal (roads, the bridge, and the tunnels), the central and eastern parts have also found a more robust integration. Although these connections will improve the integration of the Delft-Campus station with the east side, these connections should be more. There is still weakness in connecting the south part of the city to the station.

Concerning the municipality report, it is stated that the station's location will have a variety of uses and good performance. However, It seems that except for the University leading job/ study transferring, the other functions are not particularly attractive (e.g. industries).
As figure 7 (a,b) illustrates, the east-west axis has the most choice in the station area. Due to low connections, other axes are less considered the shortest route in the city. This east-west

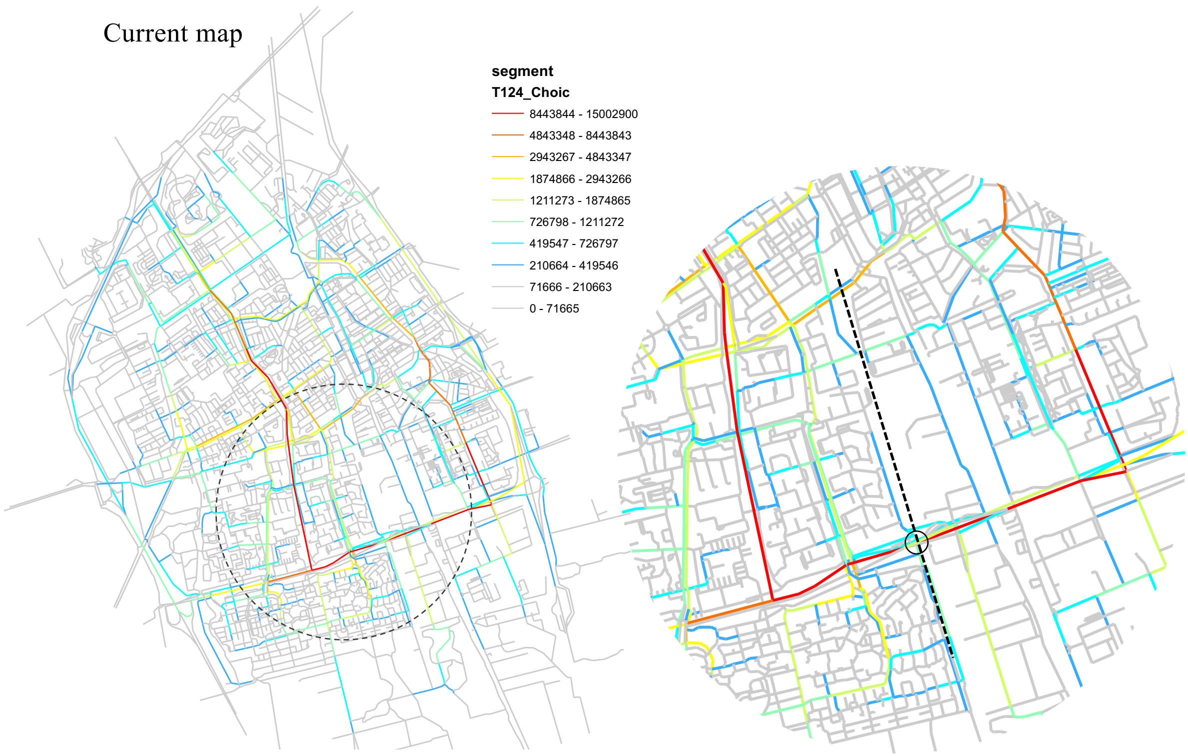

Figure7a. Segment Map of Delft; Choice of the current plan.

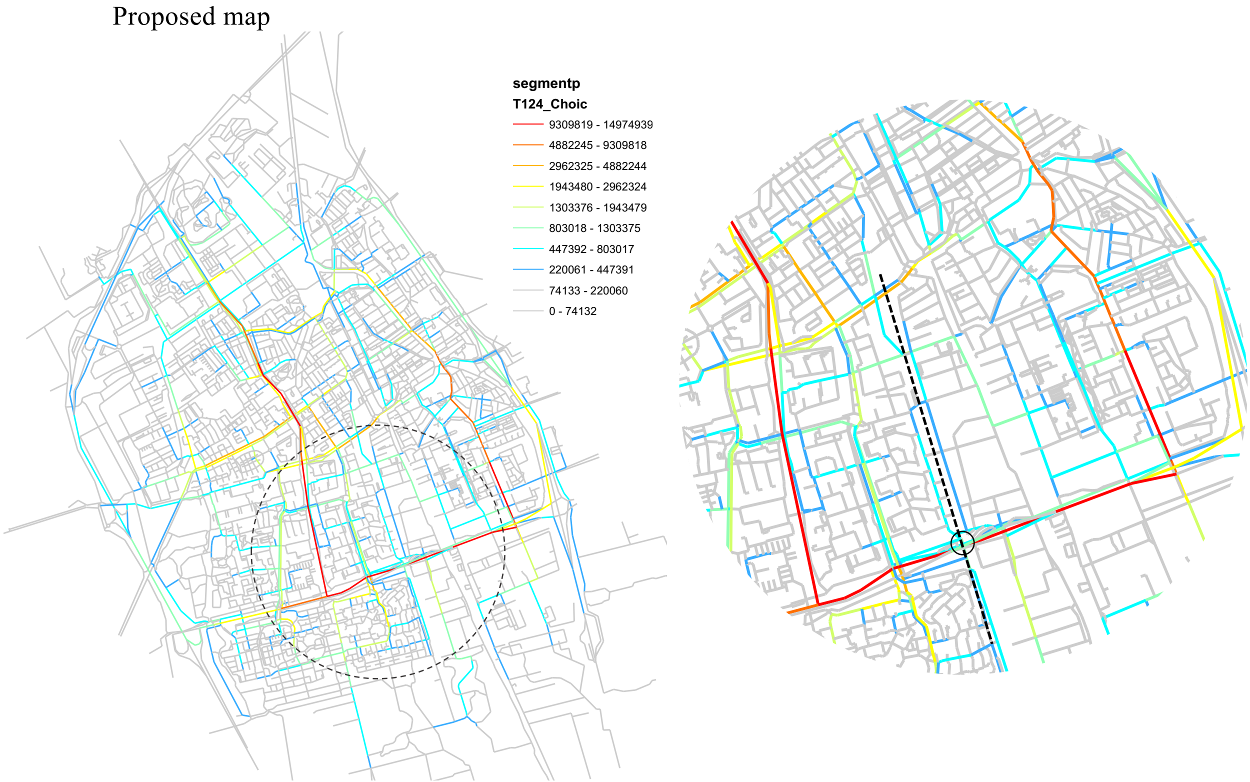

Figure 7b. Segment Map of Delft; Choice of the proposed plan.

connection is so strong that it does not make a significant difference on a large scale, even with several new axes. Therefore, comparing the current and proposed situation in the whole city and the area around Delft Campus station shows the following results: Global Choice (Rn) will be increased by implementing the approved proposed plan. Assuming only the development plan around the station is implemented, the new axes will increase the choice probability of the main

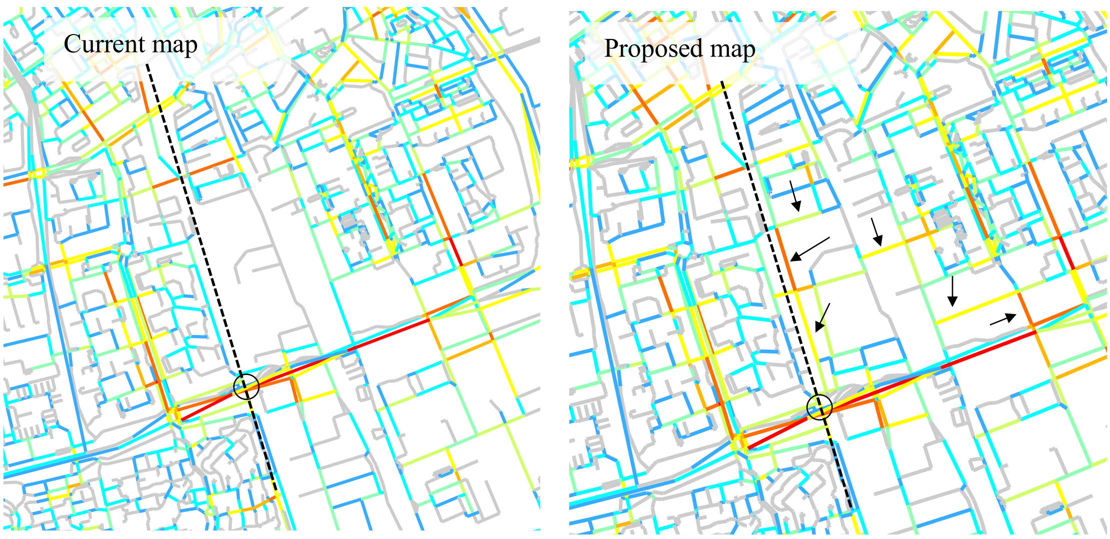

Figure 8. Segment Map of station area; local choice of the current and the proposed plan.

lines from the newly created nodes. As a result, the average choice, local and global, will be extended.

The results of local choice, the choice of routes between two nodes (with a smaller radius), show how much these new connections can affect the diversity of the choice of access routes to the station (Fig. 8).

It can be seen in table 1 that this result does not apply to the global Choice (Rn) of the station area within 1 km. The result is reversed, and the global Choice (Rn) decreases from 354337.6 to 350311.1 with new axes. The small range of connections in this area (the reasons mentioned in the integration section) has caused people to choose only a few axes globally. Moreover, this load is transferred from the previous axes to the new axes by creating new axes.

Table 1. Average local and global Choice for Delft and within 1 km area, considering the current and proposed plan.

	Average Choice for Delft		The average choice for a 1 km area	
	choice Rn	**choice R3**	**choice Rn**	**choice R3**
Current situation	250699.4	25.7	354337.6	27.4
Proposed plan of Municipality	250957.3	25.9	350311.1	28.2

However, the local choice of the station area within 1 km increased from 27.4 to 28.2. It shows that these new connections have resulted in the association of the area with the surrounding, and the local axes will be more selected. In general, the results show that the station area has few strong axes in terms of choice due to low connections. In other words, the shortest paths between different points are currently focused on one or two axes. By increasing the connections in the area, we can have several short routes to reach the station. In general, as mentioned in the

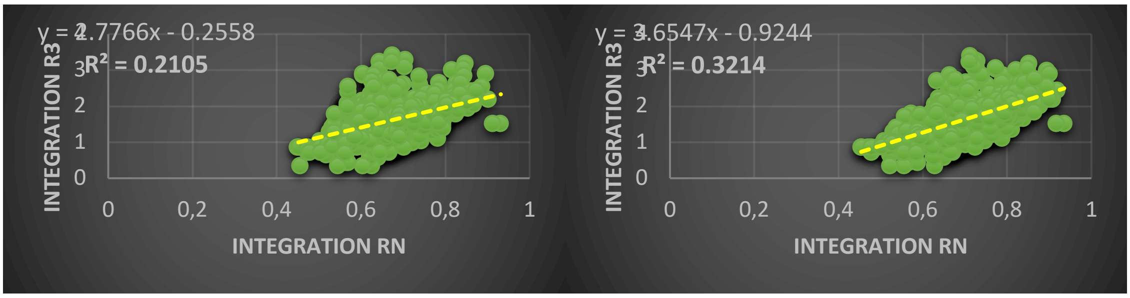

Figure 9. the scatter plots show the intelligibility of the current map (left) and the municipality proposed map (right).

integration section, the station area has poor connectivity. In addition to low integration, this problem has made the area's low intelligibility compared to the city's intelligibility. This feature is not expected for a station as an essential access/egress centre. Although the scatter plot (fig.9) shows that the implementation of approved plans will significantly extend the intelligibility of the area (R2= 0.2105 to R2=0.3214), it is not as much as it should be for the station. Accessibility refers to the correlation between integration and choice value (Asami et al., 2001; Hillier, 2001; Park, 2009; Legeby, 2013; Al Sayed et al., 2014; Topçu, 2019).

As shown in table 2, with the implementation of the municipality plans, the global and local accessibility has been increased to a small extent. However, the proposed plans have had a more tangible impact on global accessibility.

Table 2. Intelligibility and the local and global accessibility of Delft, considering the current and proposed plan.

	Accessibility	
	Rn	**R3**
Current situation	$R^2 = 0,1817$	$R^2 = 0,3761$
Proposed plan of the municipality	$R^2 = 0,1956$	$R^2 = 0,3806$

3.2 Evaluation of visual accessibility within 1km area around the station based on the municipality proposed plan

D

Analysing the visual integration and visual step depth shows that the north-south axis (Vulcanusweg and Marcellus Emantspad), parallel to the train line, has the most visual integration value, especially close to the station, at the entrance of the tunnel, the intersection of the west street and the empty area C at the north of the station, and under Kruithuisweg highway (fig.10a). Regarding these parts' high visual integration value, they could be considered for PT stations and services. The northeast part of the station, which is a part of the proposed development project, has relatively a high access and visual integration value, especially from the north side (area D), which is perpendicular to the train line. The southeast and eastern parts of the station have more visual depth and lower integration. For example, although points A and B are very close to the station, they are not well-visual integrated areas especially point A, which has more visual step depth (see fig.10a,b). The tunnel has divided the east access to the station into northeast access and southeast access. In general, due to the lack of enough direct connections and large industrial blocks, the eastern side and axes leading to the station have lower integration than the west side. Therefore, as stated in the accessibility analysis, the western part of the station is more visual and more accessible. To develop the eastern and south-eastern parts of the station, these two factors should be considered.

Places with high visual control have a high ability to dominate the spaces. As figure 10 (c) shows, most of the intersections around the station have a good visual control value. However, only a few are high and located in the high visual integrated axis. It is noteworthy that comparing this map with subsequent maps, visual step depth, and visual integration maps presented that the eastern parts of the station have limited access despite having many visual control areas. For example, on the one hand, area A has a high visual control value; on the other hand, it has a low visual integration value due to not being connected to the station directly. By providing direct access to the station and having high control, visual integration can be increased, and visual step depth can be decreased. This point and other high visual control areas can usually be suitable places for PT stations. In the case of Delft-Campus station as a small multimodal hub, the nearest areas with high visual control are preferred.

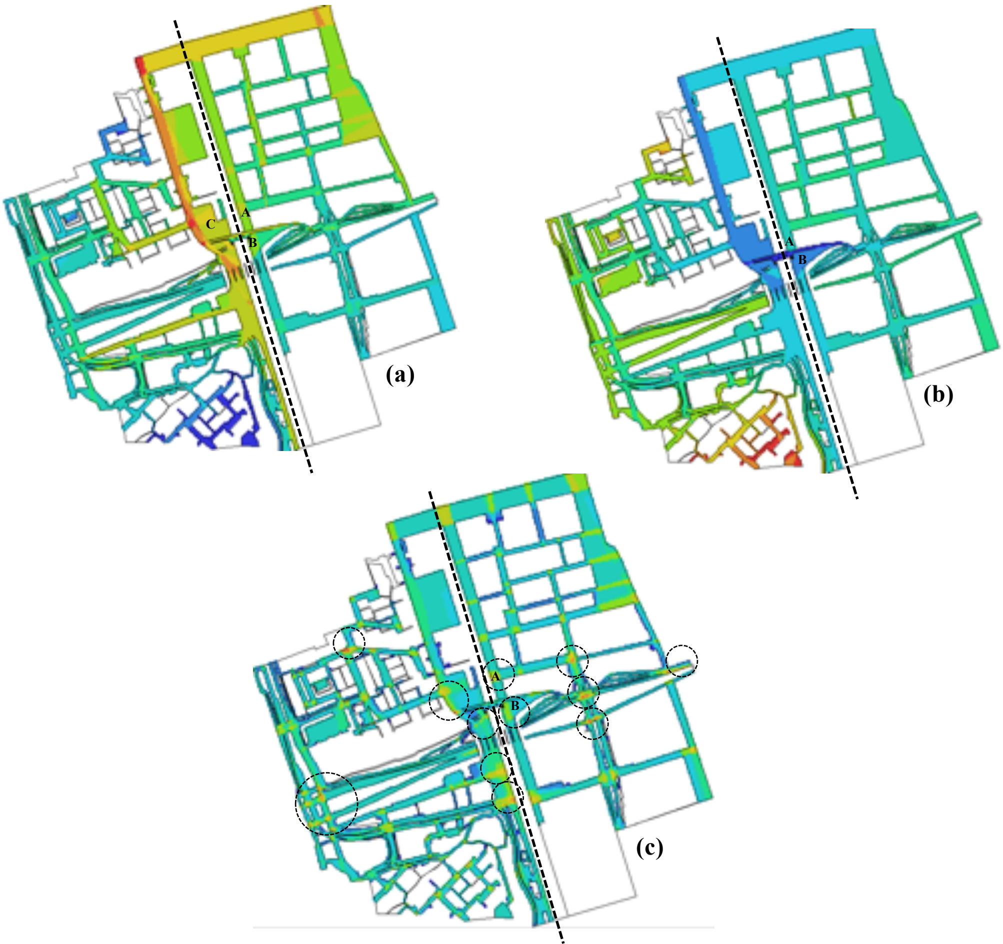

Figure 10. Visual Integration [HH] (a), Visual Step Depth (b), and Visual Control (c).

These maps (fig. 11) show the shortest paths to the station in terms of distance and angle of spaces (each cell). As these maps are defined based on the centrality of the station, the station has the shortest distance and change of angle to the whole area. Nevertheless, the remarkable point is point A. Although point A is located close to the station, it has more difficult access to the station, and the south of the station due to the lack of direct connection explained formerly.

The metric mean shortest-path angel map shows that accessing the station via the north-south axis parallel to the train line, the tunnel, and the west street from the residential area needs minor angle changes. These access lines are mainly distanced in the shortest path from the station. The right map clearly shows that areas A and B need to pass more metric mean angles in the shortest path accessing the station, unlike proximity to the station.

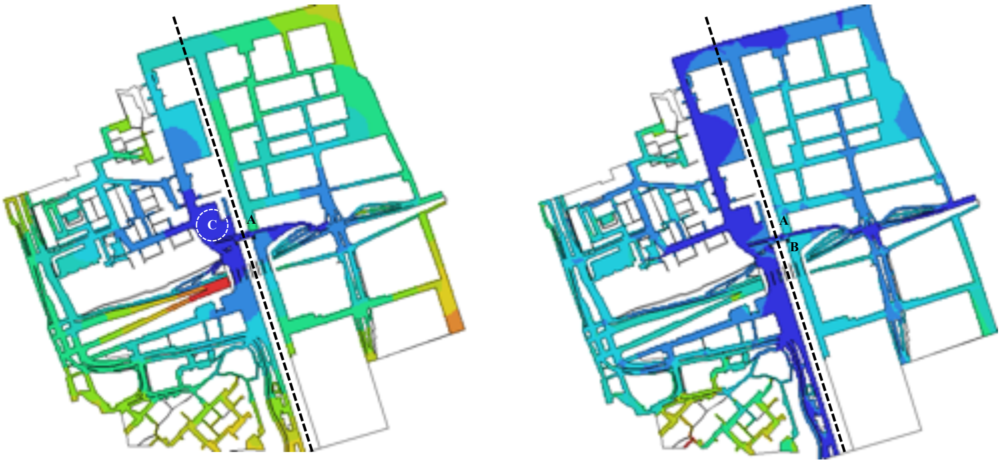

Figure 11. Metric Mean Shortest-Path Distance (Left) & Metric Mean Shortest-Path Angle (Right).

4 CONCLUSION

A multimodal hub should be located in the most integrated and accessible area for different transport modes. Every proposed development plan especially for the station surrounding areas has side effects. Because these plans have not been implemented yet, they cannot be evaluated empirically. The space syntax models provide the opportunity to evaluate the current situation as well as predict and test different design proposals in order to find out where and which kind of measures should be implemented. So before arriving emerging access/egress modes, analysing the proposed development plans' impacts on accessibility and seamless mobility is crucial.
We investigated the impacts of the spatial configuration of a city on accessibility of a small-hub train station (Delft-Campus in the Netherlands) and seamless mobility within the hub before and after the development plans. By analysing physical and visual accessibility of multimodal hubs based on the space syntax theory and DepthmapX software, this paper provides insights regarding the importance of proposed development plans which are essential for designing every multimodal hub considering emerging modes.

From the global and local segment analysis, the maps presented relatively low current local and global accessibility. In general, the results showed that Delft-Campus station is located on Kruithuisweg, the most integrated road in the city, but it is not located at the most integrated intersections. Due to some spatial limitations, the station is neither well-connected and well-accessible in the city, nor well-integrated and well-oriented within the surrounding area.

Delft-Campus train station is the central train station for Delft University of Technology (TU Delft) and experiences pedestrian volume; however, its integration value is low. It shows that the University is one of the dominant factors in determining the movement pattern of people that require more convenient access/egress modes to support mobility. The station suffers from the lack of public transport modes and facilities such as shops, restaurants, cafés, and recreational activities due to the existing large size of industrial buildings and the (vacant) office buildings in the surrounding.

With respect to the municipality report, implementing the new plan and increasing connections will increase the global and local integration in the city. In general, although these problems have been partially addressed in the proposal plan, it still seems necessary to increase connections to the station, especially from the south and east sides, in order to improve the intelligibility and accessibility of the station within surrounding and in the city.

Visual graph analysis showed that the north street (Vulcanusweg and Marcellus Emantspad), parallel to the train line, is the most robust axis in visual integration, visual step depth, visual control, and metric mean shortest-path distance and angle. Then, the station is relatively visible from the west, the south, and the tunnel. However, the visual accessibility from the east side is not well-provided due to the lack of enough connections and existing of large blocks. Besides, the tunnel has divided the direct north-south access from the station's east side, which should be taken into account. These two areas and the north empty space have high development potentials in the station’s periphery.

In conclusion, the space syntax method is a reliable analysis method to predict the side effects of the proposed development plans for stations which should be considered for urban design and planning projects. Besides physical and visual accessibility of a multimodal hub, the impacts of technology-emerging alternative modes should be given more attention by policymakers, planners, and designers in the coming years. It can be generalised that well-accessible and well-integrated multimodal hubs including a good combination of emerging modes besides walking and cycling and services, can provide attractive multimodal hubs and encourage using public transport modes instead private cars especially for short-distance trips.

To improve the municipality proposed development plan, some recommendations are listed in the next section.

5 RECOMMENDATIONS AND DISCUSSIONS

This study provides the following recommendations to improve the station's accessibility in the city and seamless mobility within the station area, considering the municipality proposed development plan.

- Providing recreational activities, shops, cafés, restaurants, etc., will promote attractiveness and opportunities within the station area.
- Increasing the variety of access/egress modes at station is necessary, especially emerging modes in the station's different entrances (directions).
- Providing better-designated pedestrian path in order to improve pedestrian accessibility.
- Providing more connections to the station from east and south sides, e.g. connecting Van Den Broekweg to schieweg and Heertjeslaan to Fadadayweg through new bridges.
- Connecting Schieweg-Noord (northeast axis) to Schieweg-Zuid (southeast axes) directly by continuing the new connection along the rail line to the south for pedestrians (connecting area A to area B).
- Providing ease of orientation within the city upon leaving the stations
- Providing ease of orientation for users to find the modes
- Providing emerging PT stations at high integrated and accessible axes
- Providing PT stations at areas with high visual integration and visual control and less distance and angular changes to the station
- Improving the east visual access and providing some emerging PT stations there.
- Providing emerging PT stations on both sides of the tunnel (east and west).
- Locating the most preferred mode (shared bike) close to the tunnel, in the north square and under Kruithuisweg highway.
- Using the north public space (area C) for emerging PT stations and services

This research presented that the municipality proposed plan has improved the station's position in the city network and local scale. However, to have a well-accessible multimodal hub, physically and visually, it is suggested that these recommendations should be tested in space syntax and VGA to confirm the most accessible plan. This investigation should be studied in further research. In addition, these findings will be used to design multimodal hubs considering emerging access/egress modes and related services to increase seamless mobility within the station. So, It is recommended to explore the impacts of the emerging modes on the spatial design of multimodal hubs for future research. Furthermore, some site observations are needed to validate the data. Moreover, to generalise these findings, the physical and visual accessibility of different train stations should be analysed and compared globally and locally.

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