U.PORTO

FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

TRANSIT-ORIENTED DEVELOPMENT

Evaluating the F line of the Porto metro system using node-place model and pedestrian accessibility

SHADN SAID

Thesis report submitted in partial fulfilment of the requirements for the degree of

MASTER IN SPATIAL PLANNING AND URBAN PROJECT

Supervisor: Cecília do Carmo Ferreira da Silva

PhD Professor at the Faculty of Engineering of the University of Porto

Co-Supervisor: David Sousa Vale

PhD Professor at the Faculty of Architecture of the University of Lisbon

JULY 2018

MESTRADO EM PLANEAMENTO E PROJETO URBANO 2015/2018

DEPARTAMENTO DE ENGENHARIA CIVIL

Tel. +351-22-508 1903

Fax +351-22-508 1446

✉ mppu@fe.up.pt

Editado por

FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Rua Dr. Roberto Frias

4200-465 PORTO

Portugal

Tel. +351-22-508 1400

Fax +351-22-508 1440

✉ feup@fe.up.pt

http://www.fe.up.pt

To my supervisor,

I thank you for your efforts and patience. Your guidance helped me to development my academic skills.

To the coordinator and all the academic staff in urban planning department,

Your lectures gave me the important knowledge to complete this work successfully.

To the scholarship program Global Platform for Syrian Students,

I thank you for this golden opportunity.

To my parents: Prof. Ibrahim Said and Prof. Amira Aumari,

No words can describe my sincere gratitude. You are my touchers and role models.

To my siblings: Mazen and Sali,

You are the joy of life. I continued this journey thanks to your help in boosting my morales and keeping me motivated.

To my country Syria,

I wish this work will help in rebuilding process based on scientific foundations to achieve prosperity and progress for the surviving Syrian people.

ACKNOWLEDGMENTS

I would like to acknowledge with gratitude my supervisor Professor Cecília Silva for the great effort she has made with me and the guidance she has given me to accomplish this work, wishing her lasting health and success. I also thank my co-supervisor Professor David Vale for his valuable remarks and guidance that helped to complete this work. I extend my sincere thanks to the University of Porto and all the academic staff at the Faculty of Engineering that supported me and provided me with all the appropriate means and conditions to obtain a Master's degree. I will never forget the credit of the scholarship program, Global Platform for Syrian Students, that is provided by former President Jorge Sampaio (wishing him good health and happiness), to get me a chance to study in this beautiful country –Portugal. Furthermore, I am grateful to Dr. Helena Barroco that supported me all the way –since my arrival to Portugal- (May she be showered with happiness) until I obtained my Master’s degree.

Finally, I am deeply grateful for my family, starting with my parents who there with me step by step on every moment of this work, guiding me to accomplish one of my main objectives in life; my brother who stood up by me every time I was down to make me continue this journey and my sister who was proofreading and helping in translating this work. This research would not have been completed without them.

RESUMO

A dependência do automóvel ainda é considerada um problema, apesar do desenvolvimento, multiplicidade e diversidade da oferta de transporte público. A falta de integração efetiva dos usos do solo com os transportes pode prolongar o problema. O desenvolvimento orientado para o transporte público (TOD) é adotado como uma técnica para alcançar um equilíbrio entre a procura de transporte e a procura de uso do solo, com vista a melhorar a acessibilidade pedonal das estações de transportes públicos. O modelo *Node-Place* é uma ferramenta para classificar as estações que alcançam esse equilíbrio, onde o índice de *Node* indica a facilidade de acesso a uma estação através de transporte público e o índice de *Place* indica os usos urbanos na área de influência da estação. Segui a metodologia da Vale (2015), combinando o modelo *Node-Place* com acessibilidade pedonal (*Pedshed*) apliquei-o à escala metropolitana do Porto em Portugal, utilizando as estações da linha de metro Fanzeres-Senhora da Hora (linha F). Em geral, os resultados mostram que as estações que estão localizadas no centro do Porto têm altos valores de índices de *Node* , *Place* e *Pedshed*, enquanto as estações periféricas são consideradas desequilibradas. Este resultado é útil para fazer uma comparação em termos de oferta de transporte e atividades urbanas das áreas das estações e sua integração com a facilidade de andar a pé, e assim, procurar os procedimentos adequados para alcançar o equilíbrio e reduzir o uso do automóvel.

ABSTRACT

Car dependency is still considered an issue despite the development, multiplicity and diversity of public transportation. Lack of effective integration of land uses with transportation may prolong the problem. Transit-oriented development (TOD) is adopted as a technique to achieve a balance between the transportation supply and land use demands with a view to enhancing walkability in transport stations. The node-place model is a tool to classify stations reaching that balance, where node index is all that allows to access a station area via public transport, and place index is the land use characteristics in a station area. I followed Vale's methodology (2015) by combining node-place model with pedestrian accessibility and applied it to the metropolitan scale of Porto in Portugal, using Fanzeres-Senhora da Hora metro line (F line) stations. In general, the results show the stations that are located in Porto center have high node, place and pedshed indexes values while the peripheral stations are considered unbalanced. This result is useful to make a comparison in terms of transportation supply and urban activities of stations areas and their integration with the walkability degree, and thus making the appropriate procedures to achieve balance and reduce the use of cars.

KEYWORDS: Transit-oriented development, node-place mode, walkability and Porto metro.

INDEX

FIGURES INDEX

TABLES INDEX

ABBREVIATIONS

TOD – Transit-Oriented Development.

TAD – Transit-Adjacent Development.

PedShed – Pedestrian Shed.

STCP – Sociedade de Transportes Colectivos do Porto.

CP – Comboios de Portugal.

1 INTRODUCTION

Overly car dependence has become a rising problem in the suburbs (Reusser et al., 2008; Bertolini, 2008). Reducing car use is one of the most important steps taken in the development process of those areas. One of the primary car alternatives is the railway found in cities and suburbs, as this system operates a high number of journeys with multimodal links (Renne, 2009; Reusser et al., 2008). Nevertheless, this is not sufficient as the spatial distance between activities, functions, and services requires travelling (Kamruzzaman et al.,2014), which calls for the need to build transport systems that outdo cars in speed and capacity (Jain et al., 2014). In addition, developing areas surrounding railway stations, where place and transport activities correspond to each other, is a crucial way towards urban development that utilizes transit-oriented development (TOD) as part of it (Bertolini, 2008; Reusser et al., 2008; Renne, 2009). The latter reorganizes the place on environmental, social, economic, aesthetic and service-oriented bases, provides mixed land uses (residential, commercial, entertaining, service-oriented, and institutional), and improves public transport services, including constructing a criss-cross street network that facilitates reaching the place and using its services and activities within an area not exceeding 10 minutes of walking that equals a distance of no more than 800m from the transit station (Jacobson and Forsyth, 2008; Kamruzzaman et al.,2014; Vale, 2015).

While both Transit-Oriented Development (TOD) and Transit-Adjacent Development (TAD) are concerned with mixed land uses and improving public transport services, the latter focuses on physical proximity to the station, whereas the former works on founding a pedestrian-friendly environment (Vale, 2015; Renne, 2009). Hence, TOD boosts the performance of functions and saves money and time during travelling to reach services, to the satisfaction of people, as it also pays attention to the aesthetical details of the place because of its concern with built environment which encourages walking (Kamruzzaman et al., 2014).

In this way, TOD solves some of the social problems that suburbs have such as public health concerns and social exclusion (Reusser et al., 2008). That TOD is a place for proper human living and interaction is the conclusion that the National Association of Realtors and Smart Growth America arrives at in a survey across USA that reveals that 61% of people intending to buy houses are looking forward to live in neighborhoods characterized by a smart growth which TOD is part of according to Levine's study in 2006 (as referenced in Renne, 2009). Another study mentioned by Renne (2009) states that between 10 and 25% of families in USA require TOD. Thus, it follows a policy of sustainable urban mobility (Vale, 2015).

Recent studies are concerned with measuring the degree of integration between land use and transport in TOD's area. Node-Place Model is used to achieve a balance between land uses and transport (Chorus and Bertolini, 2011). This research aims to measure the degree of balance behavior of the F line stations in Porto metro network, guided by the methodology that follows Vale's of 2015, and using the node-place model and its indexes. The place index is the land uses' characteristics in the station area, while the node index allows accessibility to the station via public transport. The model is enhanced by Pedestrian shed ratio (PedShed ratio) index to measure the accessibility area within distance of 500m from the station. Cluster analysis is used to classify the stations, allowing to learn of the necessary procedures to achieve the balance between the characteristics of the place and transport.

The chapter two is a transit-oriented development literature review. It shows historical background, definitions of TOD, its benefits and investigates the difference between Transit-oriented development (TOD) and Transit-adjacent development (TAD), followed by TOD typology and its characteristics. Furthermore, the chapter two gives an outline of the Node-Place Model and the walkability factor. The chapter three explains the research methodology. The chapter four gives a brief background of the case study and data collection. The chapter five discusses the results. The chapter six is the conclusion.

2 Literature View

2.1 TRANSIT-ORIENTED DEVELOPMENT (TOD)

After the expansion of streetcar and rail systems, in 19th century urban planning became oriented towards communities that rely on streetcar lines as the mean transportation. which was the basic of some American cities; such as Boston. those cities are considered as “legacy” of urban development based on transport mass (Jacobson and Forsyth, 2008). In the late 19th and early 20th century, strategies of building urban communities along with constructions of streetcar network were applied as Garden city concept (Jacobson and Forsyth, 2008; Papa and Bertolini, 2015). After the second world war, in some European parts, urban planning became oriented towards developing suburban areas to satellites[1] communities along transit lines (Papa and Bertolini, 2015). All of these approaches were connected to the need to solve urban sprawl and TOD appeared in USA as the result of all the evolving previous experiences along the years as a part of New Urbanism and Smart growth approaches to minimize urban sprawl by improving land uses along with increasing the transport supply to reduce car dependency (Jacobson and Forsyth, 2008; Papa and Bertolini, 2015).

In nineteens, Peter Calthorpe presented and codified the Transit-Oriented development concept in his book “The Next American metropolis” (Carlton, 2007). However, Jacobson and Forsyth (2008) mentioned in their literature review that many authors have endeavored to give Transit-oriented development a designation in several terms, including “transit villages”, “transit-friendly design” and “planned, balanced communities” (Vale, 2015). Such definitions, in Cervero’s view are subjective (Renne, 2009). Yet, Jacobson and Forsyth agree that Calthorpe’s definition of TOD is the most inclusive description: “A Transit-Oriented Development is a mixed-use community within an average 2,000-foot walking distance of a transit stop and core commercial area. TODs mix residential, retail, office, open space, and public uses in a walkable environment, making it convenient for residents and employees to travel by transit, bicycle, foot, or car” (Calthorpe, 1993, p. 56; as referenced in Jacobson and Forsyth, 2008).

Thus, TOD is better in using lands, developing transit stations and their connectivity as well as human interaction according to Kamruzzaman et al. (2014). It raises the place value in terms of diversity in land uses and its economic utilization with activities that allow human interaction with the place and linking these activities directly with transit stations (transit nodes). Those nodes are connected to a well-connected network that opens access to any activity or service located anywhere within the TOD’s area itself. Therefore~~,~~ in 2005, Urban Land Institute and PriceWaterhouseCoopers ranked TOD as “a top real estate investment” (Renne, 2009).

The studies of Vale (2015), Papa and Bertolini (2015) and Chorus and Bertolini (2011) show that when a city has more diverse access model, the city economic development will increase. As an

[1] “Satellite cities were developed in the 20th century to shift the population from congested urban areas to new developments established nearby”. (Haseeb, 2017, p.6).

example mentioned in Chorus and Bertolini (2011) study of Tokyo, the transit stations that are close to CBD (Central Business District) and carry a large number of Rapid Trains and Train connections have a larger workforce than the stations that don't have this transit variety (Chorus and Bertolini, 2011). Thus, TOD increases the economic development since TOD works on developing transit connectivity and also it encourages ridership as well as increasing the commuter proportion (Papa and Bertolini, 2015). As TOD encourages walking and bike riding towards the stations it also concerned with the place environment and the effectiveness of the street network and its connectivity that contribute in that (Papa and Bertolini, 2015; Vale, 2015; Kamruzzaman et al., 2014). thus, TOD seeks to reduce cars, especially that all activities have to be at a "2,000-foot walking distance of a transit stop and core commercial area" (Calthorpe 1993, p.56, as referenced in Jacobson and Forsyth, 2008; Papa and Bertolini, 2015). in sum, Attractive, diverse place + active transit nodes ⇒ disposal of the car (boosting walkability).

Consequently, TOD integrates the developed place into the activated transit network services for achieving urban development that provides human interaction and stimulates physical activity (walking) with a clean environment of greenhouse gas emissions. Moreover, if these TODs were neighbors and connected to an efficient transport network, multi-core cities or regions would be created (Kamruzzaman et al, 2014; Papa and Bertolini, 2015).

While there are similarities between TOD and Transit-adjacent development (TAD). Both refer to an area within a circle of a 10-minute walking distance (½ mile) from the main transit station. In the literature, TOD refers to a compact, diverse area that facilitates the transit connectivity via urban design (Renne, 2009; Vale, 2015). TAD however, refers to an area that has physical proximity to transit station but without considering transit connectivity nor friendly pedestrian environment (Renne, 2009; Vale, 2015, Lyu et al., 2016). In Vale's study (Vale, 2015) on station areas of Lisbon, there was one group that was considered as "balanced TAD" stating that the place and transit station features were balanced when there is a physical proximity between the destinations and the station. However, lack of transit connectivity with poor walking conditions led the area to be qualified as TAD. In another example, Renne (2009) has made a study on three major rail stations in the East San Francisco Bay Area to illustrate examples of TAD and TOD. His study shows that, on one hand, a city that has few street links and intersections with low density and poor pedestrian environment that almost a pedestrian and bike access does not exist, represents TAD. On the other hand, a city with a high concentration in housing, jobs, services and provides pedestrian, bikes and vehicles accessibility along with streets links and intersections, has "more sustainable transport patterns for station access" (Renne, 2009, p.10), which is considered a TOD area.

However, sometimes it is not that easy to distinguish between TAD and TOD. For instance, according to Renne (2009) in his aforementioned study Hayward city is considered in-between. It is closer to TOD regarding grid street planning with a sufficient number of links and intersections providing accessibility to pedestrians and cars. However, access for bicycles is limited, which makes the city closer to the TAD model as the environment is more convenient for cars than it is for people, especially in comparison with Berkeley, which is considered as TOD.

This discussion drove Renne (2009) to identify the station area's characteristics in order to make it easier to distinguish TOD from TAD (fig. 1).

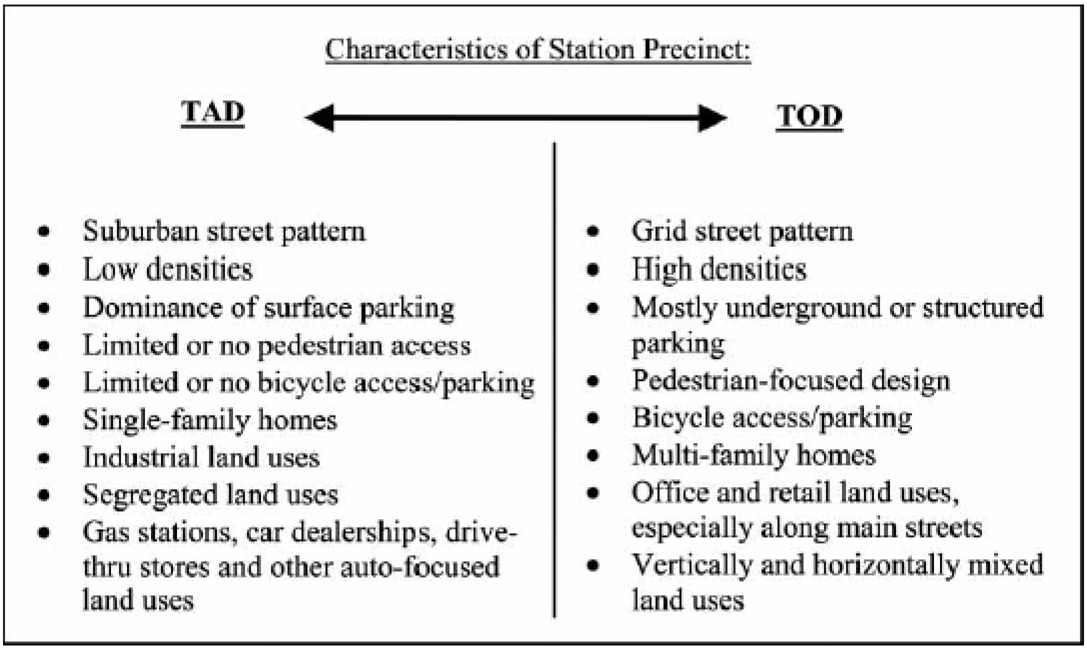


Fig. 1- The TAD-TOD differences. Source: Renne (2009, p,3)

Thus, TAD has already similar physical characteristics with TOD, thereby TAD can be TOD with increasing transit patronage, reducing car usage, and focusing on pedestrian environment.

2.1.1 Transit-oriented Development Typology

To date, there are no studies that scientifically developed the criteria necessary to assess TOD’s quality and performance to be able to have a TOD's typology; most are based on personal evaluation. Here, Kamruzzaman et al. (2014) argued that the question is no longer limited to whether the site is suitable to TOD or not but rather extends to any kind of TOD it fits, especially that TOD can take different forms and in each one it performs different functions**,** especially that it depends mainly on the characteristics of the place and the node (transit station)**.** Hence, Kamruzzaman et al. (2014) explain that the sites can be classified by scale (large city, small city or a town), location in the metropolitan area (metropolis or suburban) and by transit type (railway or ferry boat). Whereas, Lyu, G et al. (2016) clarify that the TOD's typology depends on classifying the stations morphologically and functionally (urban TOD or neighborhood TOD) "based on the main spatial orientation of the functions in the area" (Lyu, G et al., 2016, p. 42). Therefore, TOD sites would have some common characteristics as well as the classification allows comparisons to be made and evaluates TOD’s performance**,** which will help infrastructure companies to know the required procedures to develop/maintain the development process (Kamruzzaman et al.,2014).
As a result, there is an urgent need for scientific studies to develop TOD typology that would help in planning TOD in an optimal scientific way to be a strategic long-term planning tool (Kamruzzaman et al. ,2014; Papa and Bertolini, 2015).

2.1.2 TRANSIT-ORIENTED DEVELOPMENT CHARACTERISTICS

As mentioned previously, TOD's elements are the transit station (the node), which can be; the bus, metro, ferryboat or the train station, and the place that surrounds the node within specific walking distance up to 400 meters or 800 m (¼ mile to ½ mile), representing a 5 minutes to 10 min of walking. The previous discussion shows that TOD depends on place and node characteristics. TOD's place has a compact, diverse community, whereas, TOD's node has transit connectivity and various means of transport and routs that people can take towards desired destinations. At the end, all those properties should serve pedestrian accessibility rather than vehicles. As the accessibility is an important factor in the relationship between the place and station, if there is a correspondence between transit station and the place, accessibility is increased, and thereby the demand for travel increases. Among the main indicators to characterize TOD many authors agree on the importance of considering Density, Diversity, Design (the original 3Ds of Cercevro and Kockelman, 1997), Destination accessibility and Distance to Transit, which have been called the 5Ds (Singh et al, 2014).

A place that contains one type of land use imposes monotony in place (Singh et al., 2014; Kamruzzaman et al., 2014). Diversity of activities and events in the place is an important attraction for the area and especially if these activities are at different times of the day, week, or the year that increases the flow of visitors, thereby making the place more lively and socially and physically interactive, creating a safety component (Singh et al., 2014; Jacobson and Forsyth, 2008).The more the area allows the provision of public places with diverse activities, the more diverse groups are attracted, which increases the social factor, which in turn increases the housing market and thus the possibility of future growth of the area (Singh et al., 2014; Jacobson and Forsyth, 2008). Moreover, land uses diversity can achieve greater economic development. Renne (2009), Jacobson, and Forsyth (2008) argue that a high number of business establishments, landmarks or stores contributes to a larger influx of people and thus an economic benefit to the place. This is what led Singh et al. (2014) to take the business establishment level as an important factor in TOD.

Furthermore, having public facilities, services, retail, residential use and job opportunities in a small range where the distance between them does not exceed 10 minutes of walking will lead people to do their daily work on foot or ride bicycles and thus reduce the use of vehicles (Singh et al., 2014; Renne, 2009; Jacobson and Forsyth, 2008). According to Renne (2009), within a 10-minute radius of the station you will need to provide 10000 people with job opportunities, resulting in increasing the level of employment and relying on car alternatives such as public transportation, bikes and walking (Papa and Bertolini, 2015). Kamruzzaman et al. (2014) mention that studies have shown that people who live in non-TOD areas use public transportation 1.4 times less and go for walking and biking 4 times less than people who live in TOD areas. Accordingly, TOD allows for a variety of transportation modes which in turn improve accessibility, transport quality, and capacity, and diversify the passenger market (Singh et al, 2014; Jacobson and Forsyth, 2008; Renne, 2009), thereby enhancing life conditions in the area, especially by increasing transport services, viz, increases number of trips that affect the TOD's area accessibility. If transport services provide transit connectivity, it increases directions toward the desired destinations which strengthens the area's accessibility (Chorus and Bertolini, 2011; Singh et al., 2014; Jacobson and Forsyth, 2008; Renne, 2009) particularly when the spatial distribution is taken into consideration where the node location affects its services usage (Jacobson and Forsyth, 2008; Papa and Bertolini, 2015). Renne’s study (2009) shows that residents near transport stations use transport 3-5 times more than residents away from stations, while Chorus and Bertolini (2011) show that the location of the station should be close to business centers to increase revenue. In addition, studies show that spatial distribution affects land prices; the closest real estates to transport stations are the most expensive (Chorus and Bertolini, 2011). However, the healthy mix of land use is important to creating spaces that facilitate, encourage biking and walking, and contribute to spaces' preservation (Singh et al., 2014; Jacobson and Forsyth, 2008).

To strengthen walkability and biking in TOD's area, the street network's design and quality and its appropriateness for walking and biking must be considered. Increasing the intersections and street connections results in a more comfortable motion and faster access to destinations (Renne, 2009; Singh et al., 2014; Jacobson and Forsyth, 2008; Kamruzzaman et al., 2014). An important requirement to achieve such a result is the design on the human scale, i.e. the journey from one point to another has to be comfortable on foot (5-minute walking) to help encourage walking (Jacobson and Forsyth, 2008). One of the design elements on the human scale is the dimensions of the blocks: the sizes of the buildings should be small and balanced with spaces to create a convenient environment for walking. It should be noted that maintenance is an important factor at human scale, as poor design can lead to a damage that makes people avoid the place (Jacobson and Forsyth, 2008; Kamruzzaman et al., 2014). Therefore, transport stations should be attractive and comfortable, forming a shelter from the rain and strong sun rays. They ought to be bright, containing benches for sitting down and gathering (Jacobson and Forsyth, 2008; Kamruzzaman et al., 2014; Renne, 2009).
In view of what was stated previously, the place and transport station “node” characteristics directly affect destination accessibility and distance to the node, where the land-use relationship with the transport station/network is the direct measure of accessibility. The latter is, therefore, an important tool for measuring this relationship and thus identifying solutions for urban development such as increasing transit connectivity in places with high population and job density (Papa and Bertolini, 2015).

Hence, the TOD's indicators are taken from the 5Ds that have been explained earlier, such as number of commercial establishments, housing units, public utilities…, etc. Taking into consideration that the indicators vary from one study to another depending on research consistency. However, in Lyu et al. (2016) study TOD indicators are distributed using its first letters. “T” indicates transit characters; “O” indicates orientation toward the transit station. Therefore, the indictors are related to station characters. Finally, D: indicates land use characters. The appendix A at the end of their study, includes the largest possible number of indicators (see Lyu et al.,2016, p.48, appendix A).
These indicators are identified to compare between TOD's levels, evaluate TOD's performance, or reach TOD. To achieve the objectives of these indicators, they should be flexible, which means they are possible to grow or change with time. This would, in return, increase urban sustainability.

2.2 NODE-PLACE MODEL

Bertolini (1999) has established a way to organize the transit nodes (considering the site around the transit node as a part of the node) according to their development. A simple x, y diagram is drawn where x refers to the place content of an area in which the intensity and diversity of activities increase the human physical interaction. Whereas, the y refers to the transit node to which the accessibility increases that interaction.

According to Bertolini (1999), node-place model has been operationalized by Zweedijk (1997) and Serlie (1998) who developed the node and place indexes and brought them together through a MultiCriteria Analysis (MCA) (Bertolini, 1999). The node index measures accessibility to a transit station by train, bus, tram and underground, using the variables: number of directions served, number of stations within 45 minutes of travel and daily frequency of transit services; by car: distance from the closest motorway access and parking capacity; and by bicycle: number of freestanding bicycle paths and parking capacity, taking into account the diversity and intensity of the transportation supply as the main criteria.

The place index measures the intensity and diversity of activities in the area that is within 700 meters walking radius from the main pedestrian entrance to the main public transit node. The used variables are: number of residents in the area, the number of workers per each of four economic sectors (retail/hotel and catering, education/health and culture, administration and services, industry and distribution) and the degree of functional mix, which is calculated by a formula, will be mentioned later in the methodology section.

However, those variables can be changed according to the case study context. For instance, Vale (2015) took the number of stations within 20 minutes of travel, and he included the ferry boat station since it is important in traveling inside Lisbon. Moreover, in Chorus and Bertolini study of Tokyo (2011), the different variables for node index were: number of train connections (the stations that have more/multiple connections (have more passengers) leads to greater developmental potential) and proximity to CBD.

Bertolini (1999) explained that node-place model distinguishes between five typical situations of a station area (fig. 2). The “unbalanced place” reveals that the density and diversity of a place is higher than the public transportation supply, while the “unbalanced node” reveals that the public transportation supply is higher than the density and diversity of a place. The “dependence” reveals that the density and diversity of a place and the public transportation supply are both at a minimum level, while the “stress” reveals that there is a conflict between the public transportation supply and the place needs over the space (place and node indexes reach the maximum). Reaching the “balance” means node and place indexes are similar.

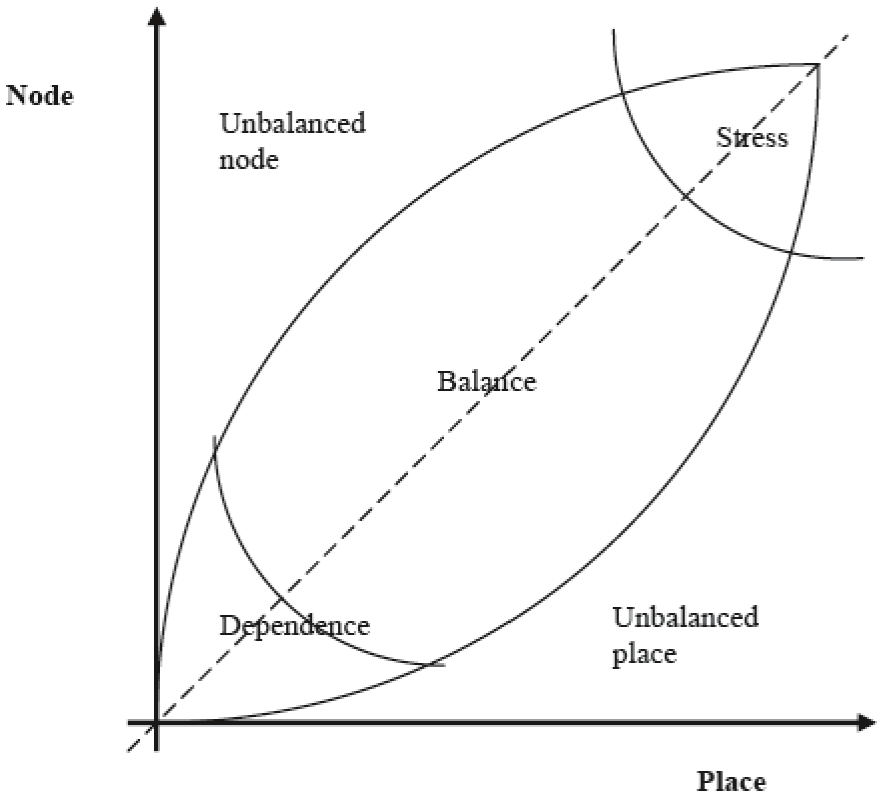


Fig. 2- Node-Place model. Source: Bertolini (2008).

The node-place diagram in figure 2 gives an idea about what the unbalanced stations need to become balanced. For instance, in the unbalanced nodes, increasing place index will create more balanced flow of passengers during all times of the day, attracting urban development. However, reaching a balanced area by decreasing the node index via reducing transportation supply in the marketing world could cause big losses. On the other hand, in order to become balanced, unbalanced places need to increase their node index, which is easier than decreasing their place index.

Thus, node-place model can give an idea of a transit station area position in urban development planning which the model can be used to understand with the necessary procedures (Chorus and Bertolini, 2011).

2.3 WALKABILITY

By walking, Human being connects the place to the node (Jacobson and Forsyth, 2008). The greater the strength of the place with its indicators (density and diversity) becomes, the more the flow of walking to the place increases, and the greater the strength of the node with its indicators (access to the node through the density and diversity of the transport supply) becomes, the more the demand for travelling grows, increasing the frequency. Therefore, in the node and place model, the place was measured in a circle within a 700-meter radius on foot from the center of the node. This is an indication that walking is an important factor in connecting the place to the node. Although all studies emphasize the importance of walking in general through recommendations concerning the human measurement and the urban form of the built environment of the targeted place and how it affects walking (Jacobson and Forsyth, 2008; Kamruzzaman et al., 2014; Park et al., 2015; Schlossberg and Brown, 2004; Vale, 2015; Renne, 2009), only few have considered walking as a type of mobility that has a supply of its own and studied the previous recommendations in detail (Jacobson and Forsyth, 2008).

The study of Park et al. (2015) illustrates how the surroundings affect walking, relying on the methodology of equations to understand whether the factors influencing the urban design of streets or walking area were sufficient to make the area structure a walkable environment. The indicators were distributed into 4 factor groups using factor analysis. The first factor is the Sidewalk Amenities; the second is the Traffic Impacts; the third is the Street Scale and Enclosure, and the fourth is the Landscaping Elements (see fig .3). Taking into consideration that this study was carried out on the so-called “path walkability”, a term coined by Park et al. (2015) to refer to “the quality of physical walking environment that can be measured objectively based on the micro-level physical characteristics of a street and its adjacent intermediary space between the outer edge of the sidewalk and the facade of nearby buildings.” (Park et al., 2015, p. 532).

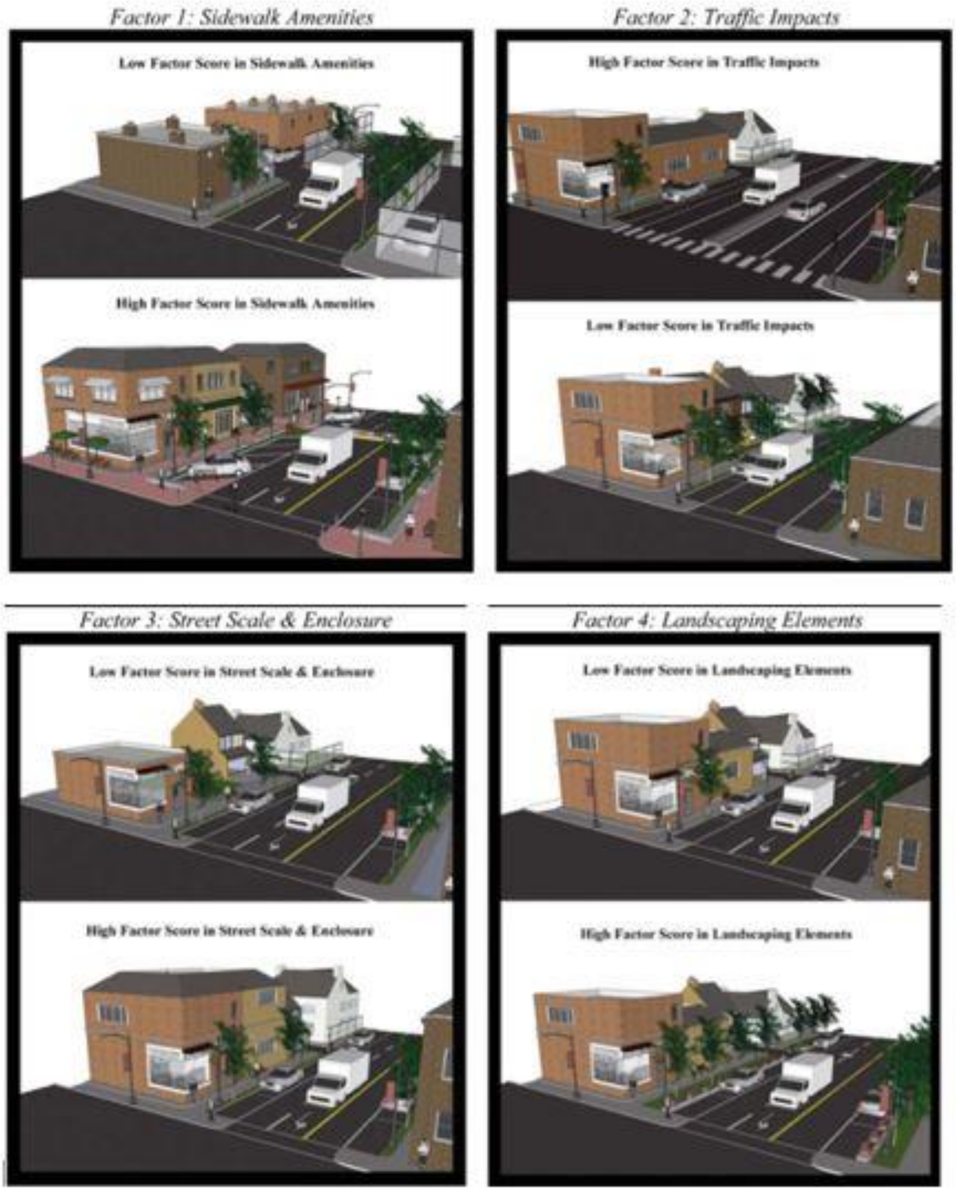


Fig. 3- Graphic interpretation of the factor analysis result. Source: Park et al. (2015).

These are but few examples that show how the attention paid to the visual appearance at human scale can make the streets narrower, congestion reduced, blocks smaller and heights lower, as well as in terms of the place attractiveness can diversify its functions, apply different colors, and avoid monotony in its form and use. This would inspire intimacy, accordingly, and tranquility on the streets and create transparency and visual horizons for activities in the area (Schlossberg and Brown, 2004; Jacobson and Forsyth, 2008; Park et al., 2015). This is on the small scale level of a street or a neighborhood (approximately 150 m) (Park et al., 2015). But this does not mean that the larger areas cannot attract pedestrians. On the contrary, according to Schlossberg et al. (2004), the areas within ¼ (400 m) to ½ mile (800 m) in a TOD area are the more pedestrian-oriented, which is TOD's main essence. In these larger areas, attention is paid to streets more than other walking factors such as the shape and quantity of roads which are equally important. For example, figure 4, taken from the study of Schlossberg et al. (2004), illustrates that the more the number of main streets and intersections in the pedestrian area increases, the poorer the pedestrian structure becomes as the main streets and intersections create wide cross-cutting, making it unfriendly in the area. In addition, too many streets located in an area not exceeding 400 to 800 meters form a traffic congestion for both cars and pedestrians. Figure 5 from the aforementioned study shows the impact of street intersections on walking. The increase in the number of links and road intersections gives more options to move in all parts of the area, thereby making the access of pedestrians to the area and to the desired destination (node) more feasible.

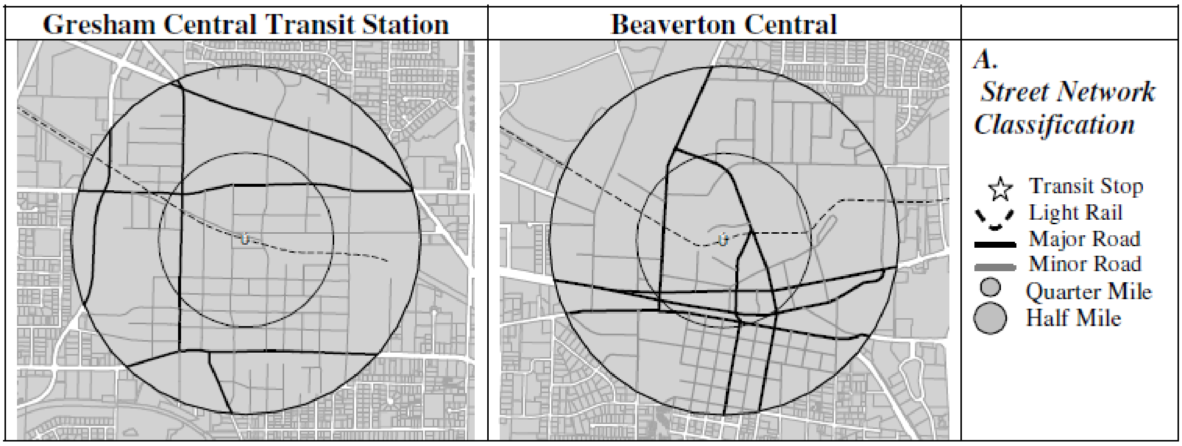


Fig. 4- Visual Comparison of TOD Walkability (A). Source: Schlossberg et al. (2004).

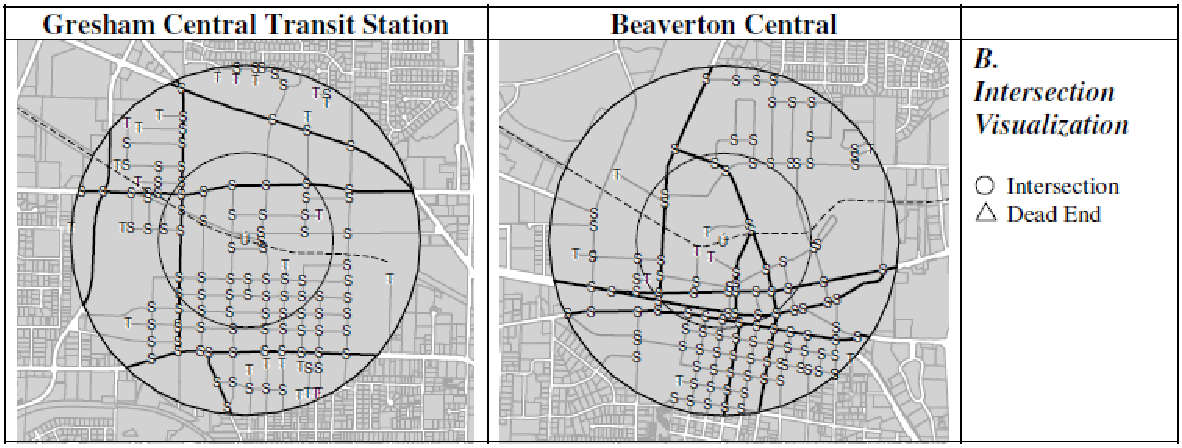


Fig. 5- Visual Comparison of TOD Walkability (B). Source: Schlossberg et al. (2004).

One of the most important elements for walking is safety which can be provided by a sufficient number of street lights, limited number of tunnels, by activating any neglected, inactive spaces or abandoned green areas, and providing various activities in the place, especially the economic ones on converged timetables to ensure movement around the clock (Singh et al., 2014). For example, according to the study of Renne (2009), the city of Berkeley that has a combination of uses leads to increasing walking frequency and the use of transport by building shops which attracts a high number of pedestrians to the place.

It is important to have a regular maintenance of facilities and streets furniture for the safety of people, as low maintenance results in leaving the area in neglect and deterioration and, therefore, reducing the safety feeling (Jacobson and Forsyth, 2008).

Thus, the pedestrian built environment contains many diverse principles that are not confined to one level, but rather range from paying attention to street networks, size, height and functions of buildings, to careful consideration of the details such as architectural features (shape of buildings) and sidewalk amenities (e.g. number of trees), all the way to benches in squares. All this facilitates the movement of humans and creates comfort. This goes under walking supplies that are of equal importance to transport supplies. Improving the urban design of places close to the station, taking into account the impact of traffic (probability of walking decreases in heavy traffic with wide crossing area), increases the probability of choosing to walk to the station (Park et al., 2015).

Briefly, the walking built environment basically relies on density (that, on a high level, enhances the lively, walkable communities and it gives a major support to a high frequency in transport service), mixed land uses (encourages encouraging people to do their daily routines on foot or bicycle) and pedestrian connectivity (increasing streets links and intersections that leads to high improve pedestrian accessibility ratio) (Singh et al., 2014).
However, there is an obvious lack of proven methodological approaches to achieve walkability at a small-scale and a lack of standard indicators that draws a clear quantitative comparison (Park et al., 2015; Jacobson and Forsyth., 2008).

3 Methodology

As Porto city is growing into a contemporary city, transport networks should fulfill people's needs with services and a suitable environment for them. Therefore, this study aims to shed light on the place, transport, and walkability conditions around the stations of the F line of Porto metro network using Vale's (2015) methodology, which is using node-place model to make the first classification of stations. The model is enhanced by Pedestrian shed ratio (PedShed ratio) index to measure the accessibility area, followed by cluster analysis to make a second classification using the three dimensions: node, place and PedShed ratio.

Initially, to calculate accessibility to a metro station, a range between 400 meters to 600 m is usually the most appropriate measure (Vale, 2018). Thus, the study area for metro stations is measured with a 500 m radius circle around every station.

To calculate node and place indexes for each station site, thirteen indicators were used (Vale, 2015), of which seven indicators are for measuring node index and six ones for measuring place index (table 1).

Table 1- Node and place indicators description.

Indicators description	Calculations	Transformation
Node index **• accessibility by metro**		
- Number of directions served	y1 = number of services offered at station	Log y1
- Daily frequency of services	y2 = number of trips departing from station on a working day	
- Number of stations within 20 min of travel	y3 = number of stations reachable within 20 min	
• accessibility by bus/train		
- Number of directions served	y4 = number of directions offered at the station	SQR y4
- Daily frequency of services	y5 = number of buses/trains departing from station on a working day	SQR y5
• accessibility by car		

- Distance from closest motorway access	y6 = distance to next highway or freeway exit in meters	
- Car parking capacity	y7= number of car lots offered by a metro station (free or paid)	
Place index **• residents**		
- Number of residents	x1 = number of residents within 500 m	
• workers		
- Number of workers in retail/hotel and catering	x2 = number of workers within 500 m in retail/hotel and catering group	Log x2
- Number of workers in education/health and culture	x3 = number of workers within 500 m in education/health/culture	SQR x3
- Number of workers in administration and services	x4 = number of workers within 500 m in administration and services	Log x4
- Number of workers in industry and distribution	x5 = number of workers within 500 m in industry and distribution	
• Functional mix		
- degree of functional mix	x6 = $1-\frac{\left(\left(\frac{a-b}{d}\right)-\left(\frac{a-c}{d}\right)\right)}{2}$ *(1)* with: a= max (x1, x2, x3, x4, x5) b= min (x1, x2, x3, x4, x5) c= $\frac{x1+x2+x3+x4+x5}{5}$ d= $x1+x2+x3+x4+x5$	

All the indicators follow the literature review for measurement of node-place model. And to identify the functional degree in a station, a formula (1) had been used (Chorus and Bertolini, 2011; Vale, 2015 and Vale et al, 2018).

After checking normality for all the variables[2], six were transformed to reduce the unevenness in their individual scores (Chorus and Bertolini., 2011), of which three were square root transformed, and the other three were logarithm transformed by SPSS software. All the indicators values were rescaled from 0 to 1 to have the same weights[3] (see annex). Then an average was calculated for place and node indexes of every station to make the node-place model classification of the stations.

The walkability analysis dimension added to the node-place model as the pedestrian shed ratio (PedShed ratio), which is the ratio between the study area defined by a circle with a determinate radius and the accessible area by pedestrian network within that same circle (fig. 6) (Vale et al, 2018, Schlossberg and Brown, 2004). The values range from 0 to 1.

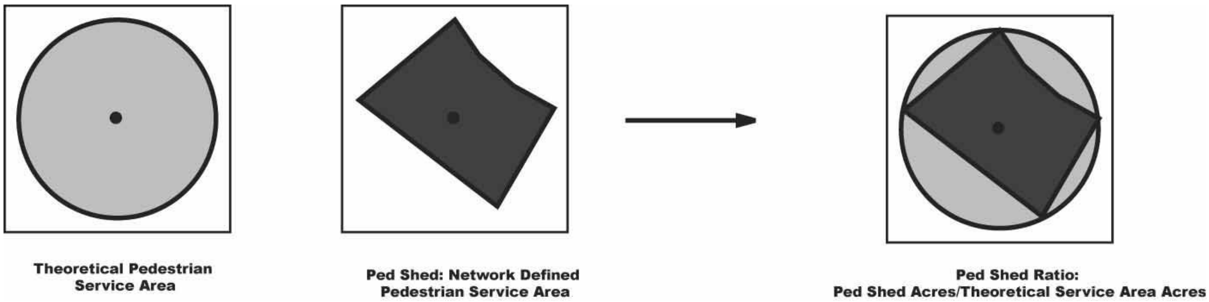


Fig. 6- Pedestrian shed ratio. Source: Schlossberg and Brown., 2004, p.6.

Thus, node, place and PedShed ratio are calculated for all the F line stations. Then an average was calculated for aforementioned indexes of every station (table 2). Finally, all the indexes are represented by the averages of the indicators (table 3).

Therefore, to develop the classification process and to elucidate the PedShed ratio effect on the classification process, cluster analysis was made (Kamruzzaman et al., 2014; Reusser et al., 2008; Vale, 2015; Vale et al., 2018) using a Two-step analysis method via SPSS software (Reusser et al., 2008). As the variables are continuous, the Euclidean distance measure is used (Hair et al. 2010).

[2] By checking the Skewness & kurtosis z-values, which should be somewhere in the span -1.96 to +1.96. (Cramer, Howitt, 2004).

[3] The used formula for rescaling: $x_{new} = {x - x_{min}}/{x_{max} - x_{min}}$.

4 Case study

Porto city is one of the cities in Porto metropolitan area (Grande Porto), located in Northern Portugal. According to national institution of statistics in Portugal, Porto city area is 41.42 km2, while Porto metropolitan area is 2041.31 km2.
Porto city has the most population density in Porto metropolitan area with 5626.8 inhabitants/km2, while it decreases to 861.78 inhabitants /km2 in Porto metropolitan area (national institution of statistics Portugal, 2011) (Fig. 7).
According to Fernandes (2011), Porto is the most attractive city in terms of employment in Porto metropolitan area. Vehicles and public transportation (such as intercity trains and metro) are the most reliable means of transport to travel to Porto within the Porto metropolitan area, whereas, commuting by foot is less frequent.

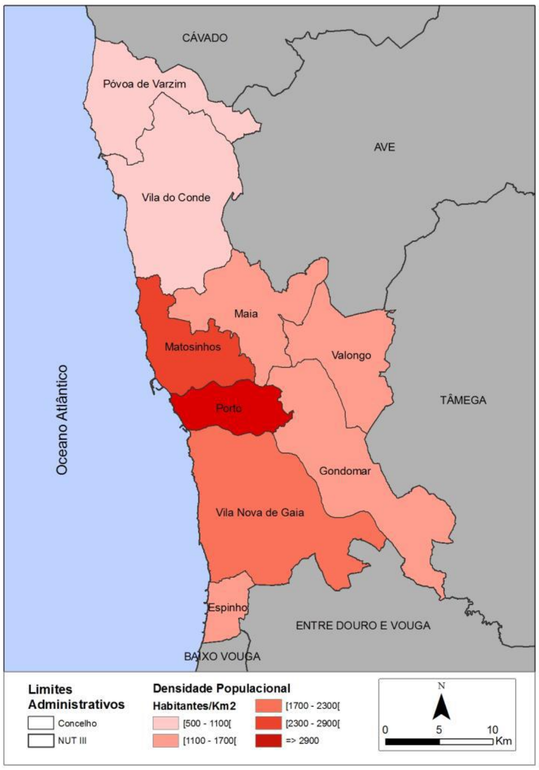


Fig .7- Population density in Porto metropolitan area. Source: Fernandes., 2011, p. 40.

The bus network which is run by STCP (Sociedade de Transportes Colectivos) covers the entire Porto city along with Metro do Porto which is one of the largest light rail networks in Europe (fig .8). It operated in 2002 with 6 lines, 102 vehicles, and 82 stations, of which 14 are underground and 7 districts integrate the network. 9000 people can be transported per hour and per line as 57.8 million validations were registered in 2017. ©Metro do Porto company has stated that 12000 cars stop circulating and 55K tones of CO_2 emissions are prevented every year by virtue of the metro.

According to ©JPN (JornalismoPortoNet)[4], the metro of Porto started as a 1990 project to reduce traffic and to link Gaia with Matosinhos via Porto as a center. However, it was extended to Maia, Gondomar, Vila do Conde, Póvoa do Varzim and Trofa. At the beginning, only 4 lines were planned to start from Campanhã to Porto Airport, Póvoa de Varzim, Senhor de Matosinhos and Trofa. Then a fifth line, perpendicular, linked Santo Ovídio to S. João Hospital. After the initial project, the network was further extended to Estádio do Dragão (due to the euro 2004) and to Fânzeres, in Gondomar.

Among the current lines, this research will focus on the F line from Fanzeres to Senhora da Hora, holding a total of 24 stations, which are: Senhora da Hora, Sete Bicas, Viso, Ramalde, Francos, Casa da Musica, Carolina Michaelis, Lapa, Trindade, Bolhao, Campo 24 Agosto, Heroismo, Campanha, Estadio do Dragao, Contumil, Nasoni, Nau Vitoria, Levada, Rio Tinto, Campainha, Baguim, Carreira, Venda Nova and Fanzeres (fig .9). Fanzeres and Senhora da Hora stations are the F line terminal, while Estadio do Dragao is the A, B, E lines terminal, and Campanha is the C line terminal. Five metro lines pass through all the stations from Senhora da Hora station to Campanha station except Trindade station which passes through all the six metro lines. All the stations from Contumil to Fanzeres provide the F line only. Trindade station is the center of the metro system as it is unavoidable to go through -along with Bolhao and Aliados (which belongs to the D line) stations - when seeking Porto downtown. While Casa da Musica station leads to Porto city center, Rotunda da Boavista.

The F line is the chosen line in this study since it goes from Porto to Gondomar, yielding various results that would benefit the used methodology, especially that the network load factor shows the contrast among the F line stations according to the Annual report for metro do Porto (2011), (fig .10).

[4] JPN is a multimedia journal of general information and permanent updating, monitoring the evolution of new communication technologies and putting into practice the most modern techniques of journalistic expression on the Internet. It is a project of the Degree in Communication Sciences of the University of Porto.

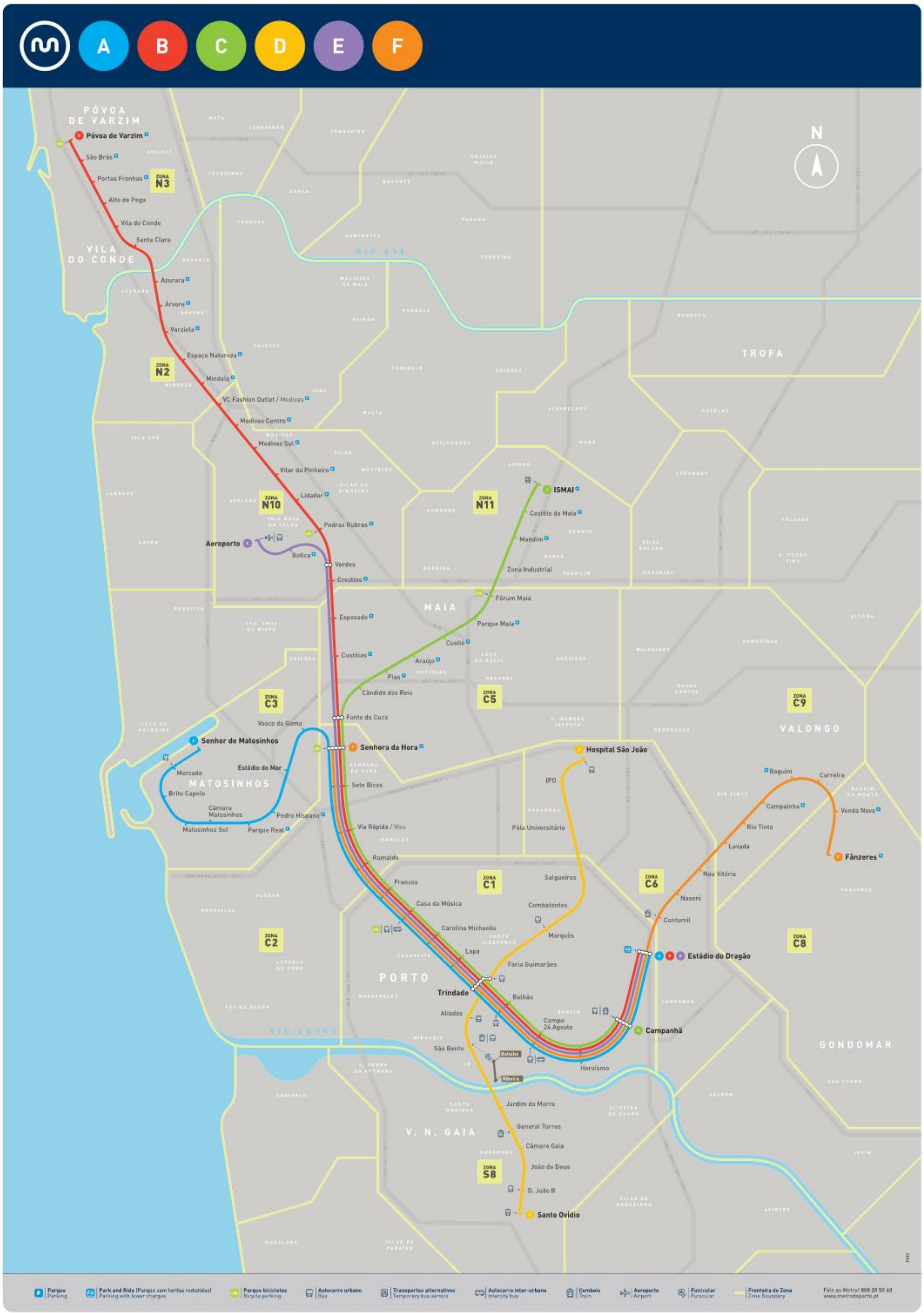


Fig .8- Porto metro lines. Source: metrodoporto.pt

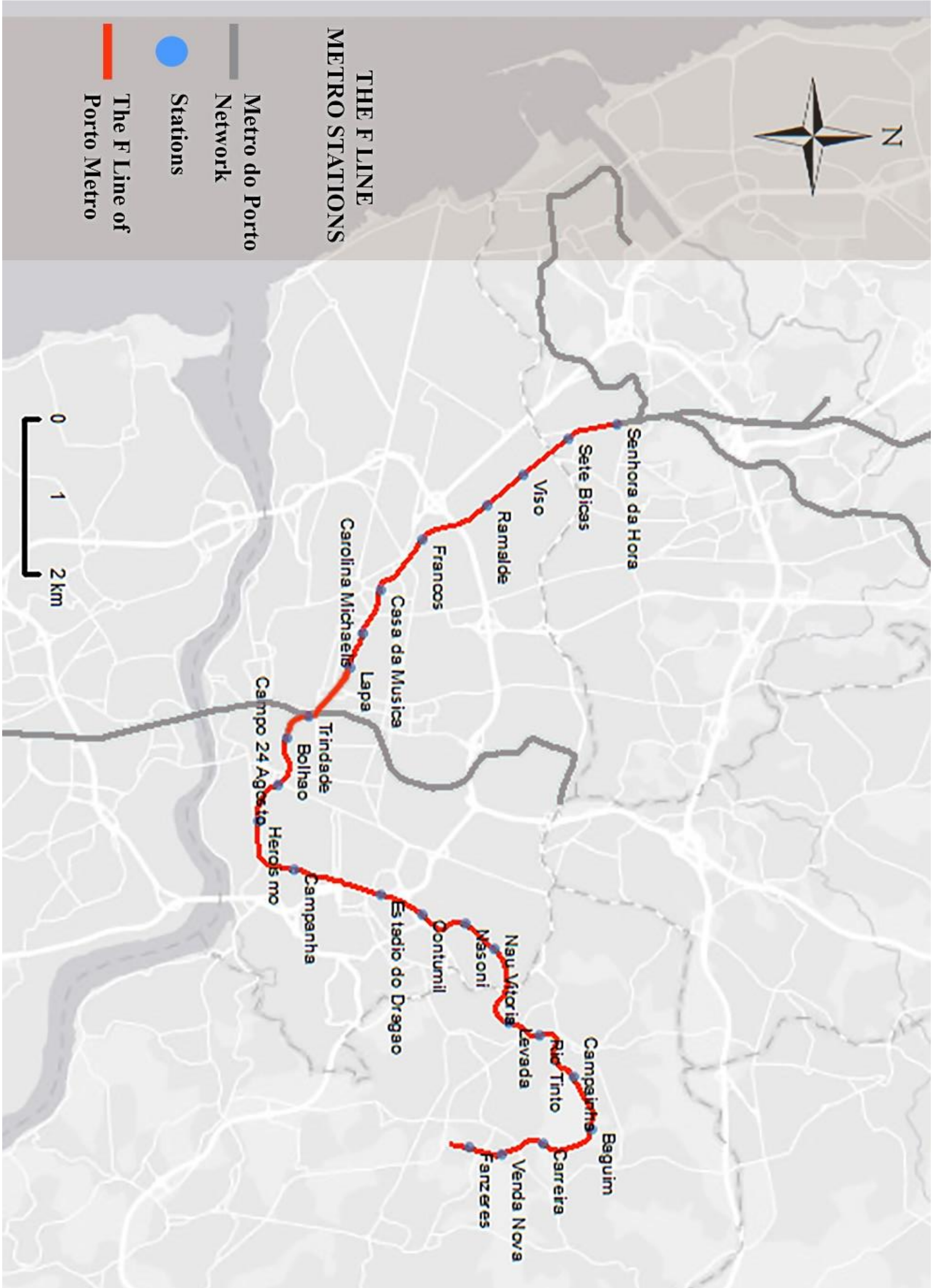


Fig .9- The F line stations from Senhora da Hora station to Fanzeres station.

Fig .10- Network load factor. It shows the contrast among the F line stations. Source: Annual report for metro do Porto (2011).

DATA COLLECTION

All the metro data was collected from ©Metro do Porto, SA and the bus data from Sociedade de Transportes Colectivos do Porto (©STCP, SA), while Campanhã train data was collected from Comboios de Portugal (©CP). All the data was collected in winter time on a working day[5]. The number of car parking is the number of free parking spaces provided by the station itself. The station Estádio do Dragão provide lower charges (Park and Ride), whereas the stations that do not provide car parking were given zero value. For place index, data is collected from Instituto Nacional de Estatística– Portugal (Statistics Portugal, 2007) and from Gabinete de estratégia e planeamento (2014), for they are the finest census data sources available in Portugal.
The pedestrian network is calculated by removing all the non-walkable segments using ArcGIS© and OpenStreetMap data. The accessible area of every station was provided by Pinho et al. (2017) analysis (see fig. 11).

[5] However, the traveling bus station in 24 Campo do Agosto was excluded due to a delay in obtaining information.

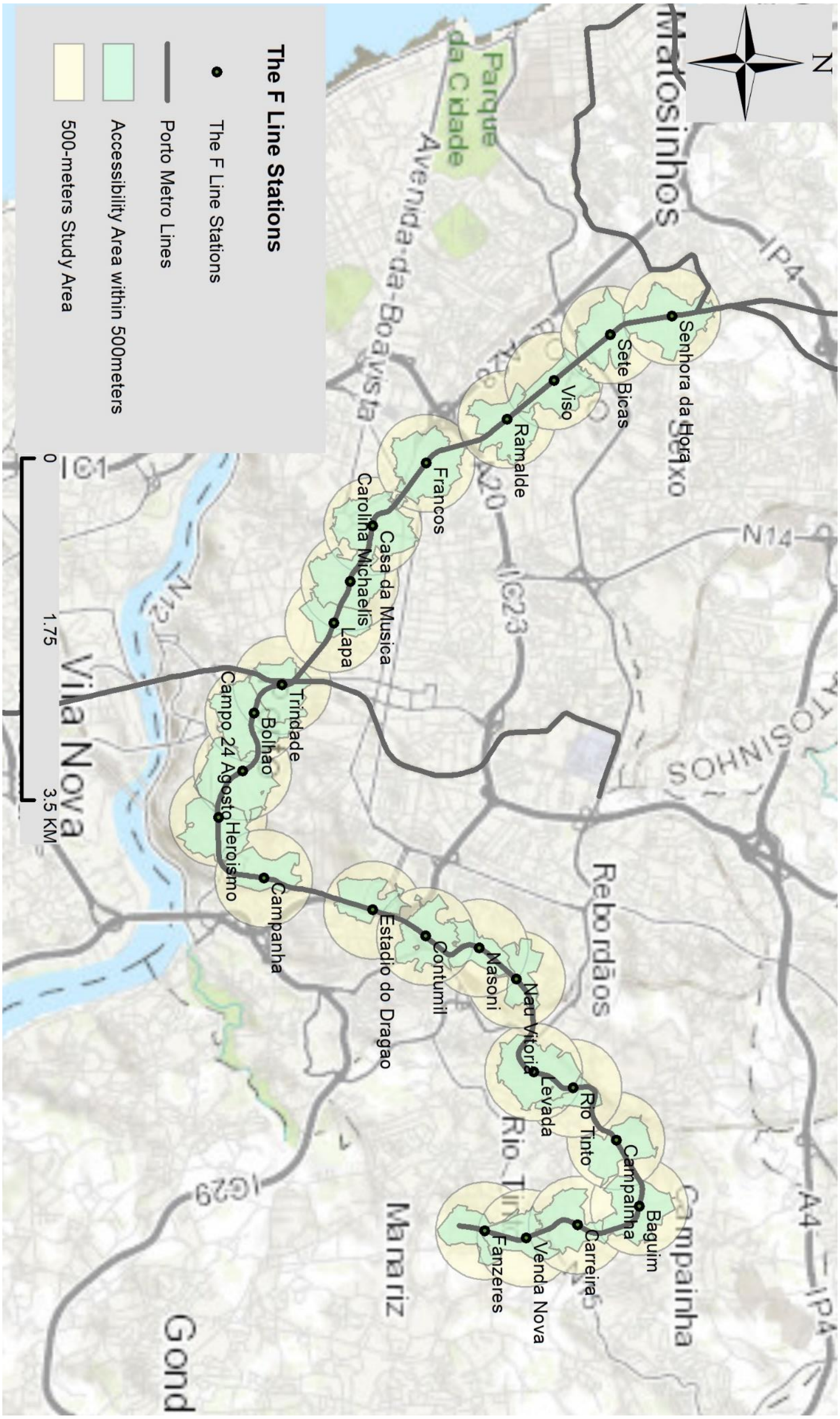


Fig. 11- Pedestrian accessibility within 500-meters of the F line stations.

5 Results

After calculating the node, place and pedshed ratio for all the F line stations, table 2 and 3 show that the place characteristics have higher impact on pedestrian accessibility in most areas of the stations, of which 16 have higher place value than the node value. For instance, there are no bus services provided at the stations located between -and including- Nasoni station and Fanzeres station (Fig. 12), although, Levada station has 1940 workers in retail/hotel and catering (x2) within 500 meters, which is considered the third highest value in this group. In addition, Nau Vitoria station is the only one that has 0 numbers of workers in education, health, culture, administration and services within 500 meters. However, it has a high number of workers in industry and distribution, meaning that it serves this group (see annex).

Table 2- The values of all the indicators for each station.

Stations	Node	Place	PedShed ratio
Senhora da Hora	0.516157	0.38769	0.506039
Sete Bicas	0.441411	0.45431	0.445272
Viso	0.536205	0.407971	0.362
Ramalde	0.48846	0.457819	0.451254
Francos	0.536742	0.52315	0.502546
Casa da Musica	0.638123	0.798091	0.520952
Carolina Michaelis	0.527577	0.548825	0.44329
Lapa	0.503282	0.522484	0.304982
Trindade	0.701763	0.800604	0.350975
Bolhao	0.700073	0.853856	0.628987
Campo 24 Agosto	0.667673	0.80292	0.568402
Heroismo	0.456412	0.571971	0.620217
Campanha	0.578907	0.675321	0.316913
Estadio do Dragao	0.416247	0.26991	0.278316
Contumil	0.233453	0.23971	0.387989
Nasoni	0.160517	0.220413	0.312779
Nau Vitoria	0.158387	0.088031	0.341321
Levada	0.17387	0.402286	0.532518
Rio Tinto	0.173577	0.215179	0.333069
Campainha	0.215714	0.241866	0.35183
Baguim	0.226407	0.043334	0.420072

Stations	Node	Place	PedShed ratio
Carreira	0.183707	0.140254	0.389113
Venda Nova	0.181104	0.277441	0.400321
Fanzeres	0.127685	0.306101	0.383342

Table 3- The final values of the indicators.

Node	Place	PedShed
0.397643881	0.427064011	0.423020841

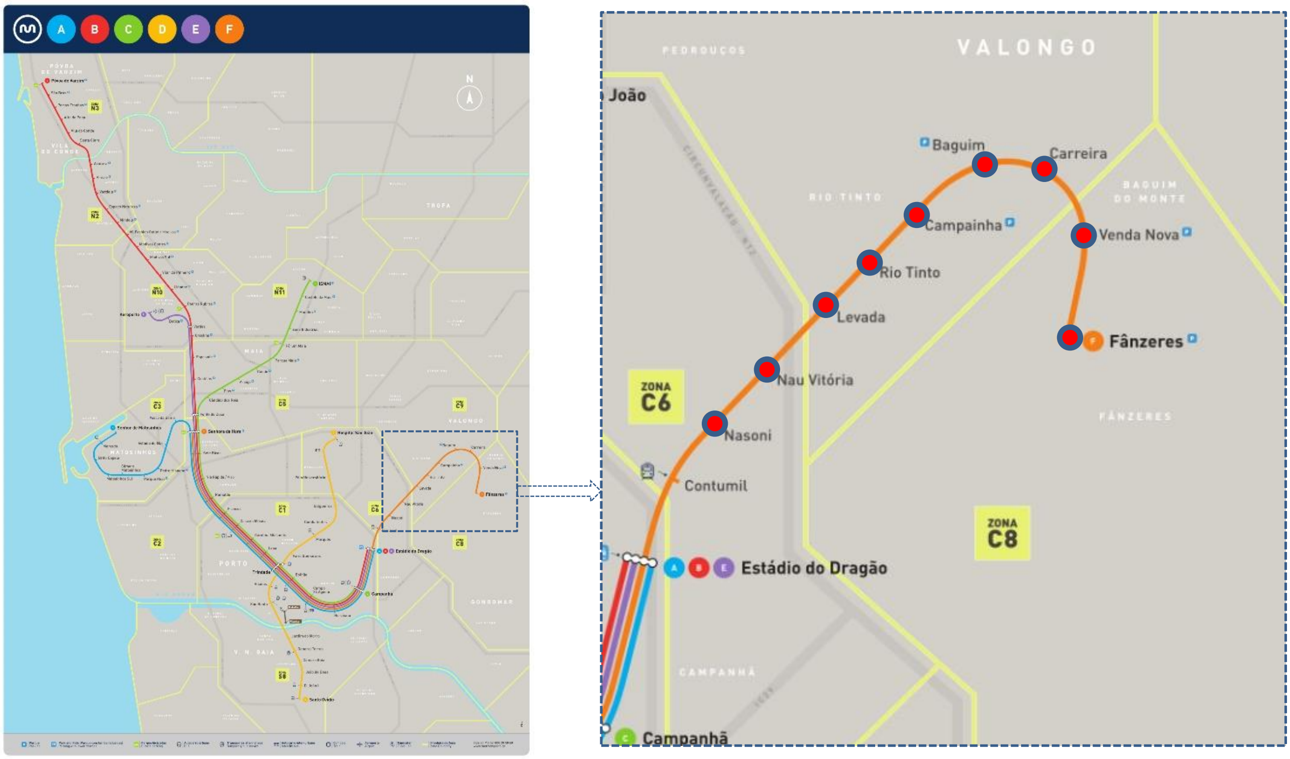
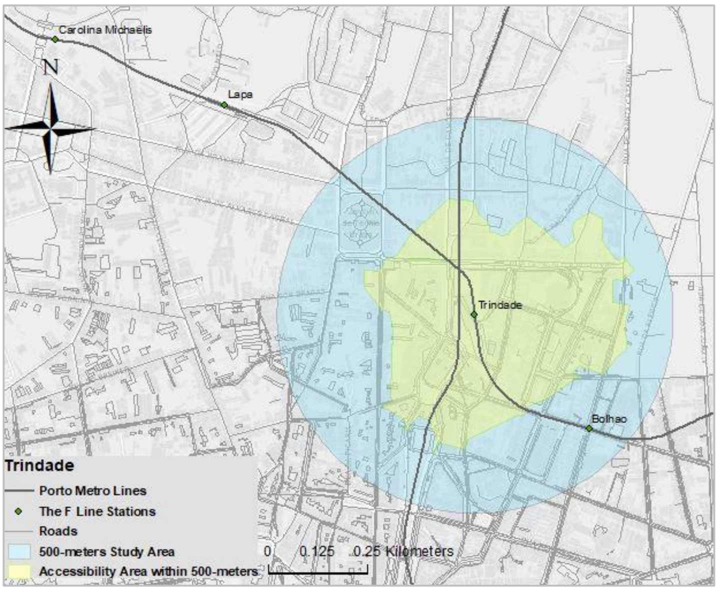


Fig .12- The stations with no bus services .

From table 2, it is obvious that Fanzeres station has the lowest node value, while Trindade station has the highest one. This result is obviouse since Trindade is a central staion in Porto and connects all the six metro lines. On the other hand, Baguim station has the lowest place value, while Bolhao station has the highest one. Regarding the pedshed ratio value, Bolhao station has the highest value, while Estadio do Dragao has the lowest one. However, the place and node values of Trindade and Bolhao stations are close to each other but there is a major difference in pedshed ratio value (see table 4 and fig. 13). By examining both place and node indexes of the stations' indicators, there is a clear difference in x2 (number of workers in retail/hotel and catering), x4 (number of workers in administration and services) and y5 (number of buses departing from station). Figure 14 shows that difference doubling in y5, x2 and x4, and whose impact would not be obvious without the pedshed ratio values. In other words, the shops and the narrow pedestrian paths that surround the Bolhao station give the site visitors a good impression, which is the opposite case in Trindade station that has big size blocks, which makes it hard for visitors to reach their destinations directly (fig. 15).

Table 4- Trindade and Bolhao stations values.

Stations	Node	Place	PedShed ratio
Trindade	0.701763	0.800604	0.350975
Bolhao	0.700073	0.853856	0.628987



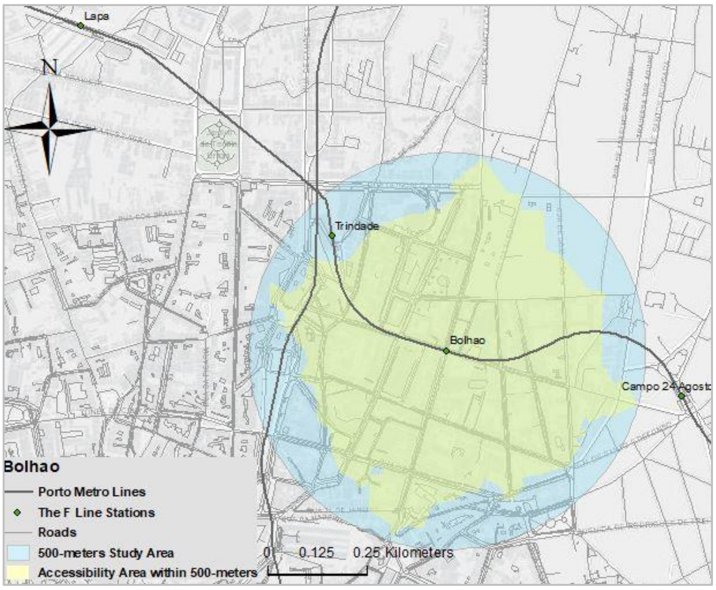


Fig. 13- The difference between Trindade and Bolhao stations' accessibility area within 500-meters.

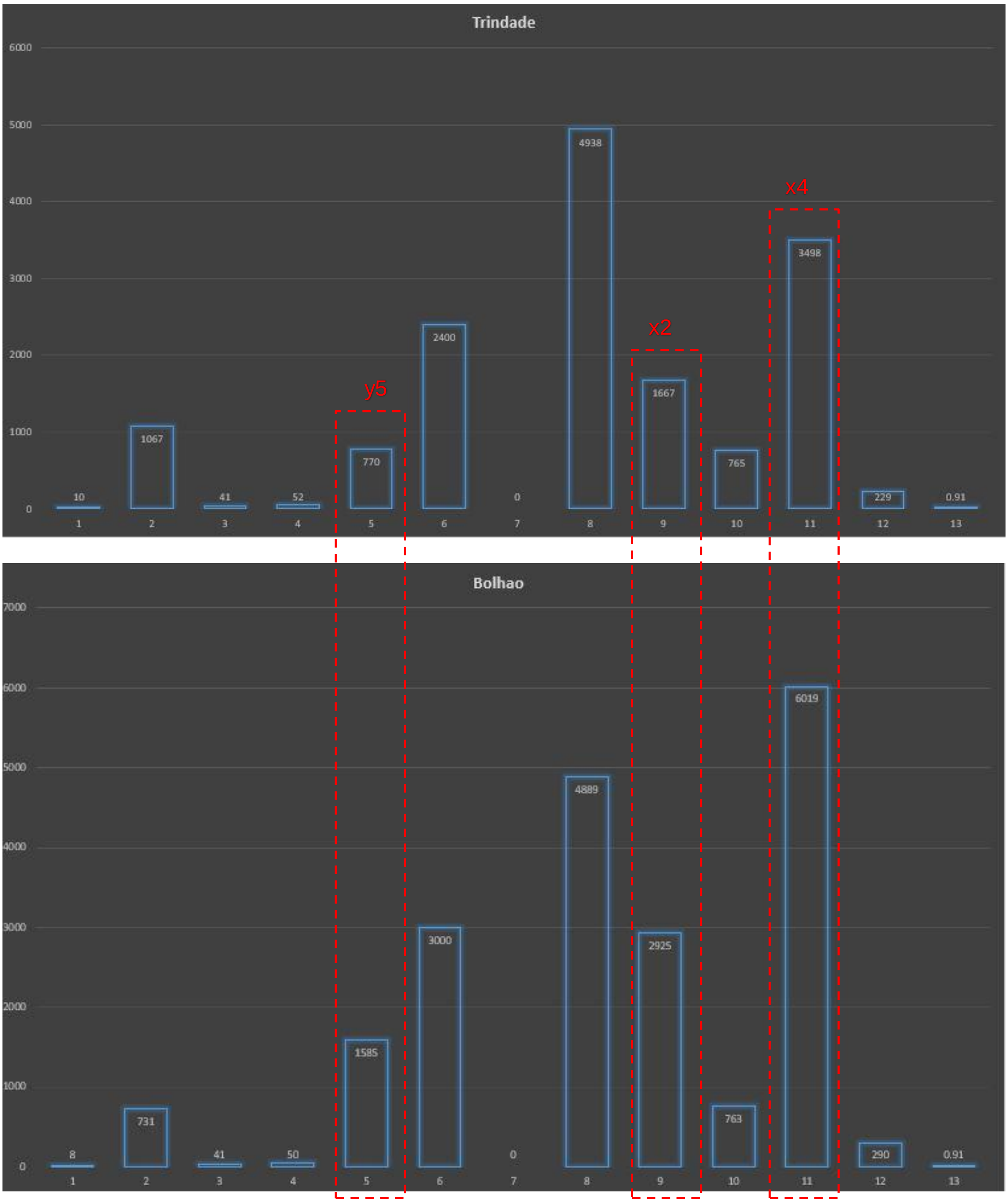


Fig .14- The differences between Trindade and Bolhao stations' indicators: y5, x2 and x4.

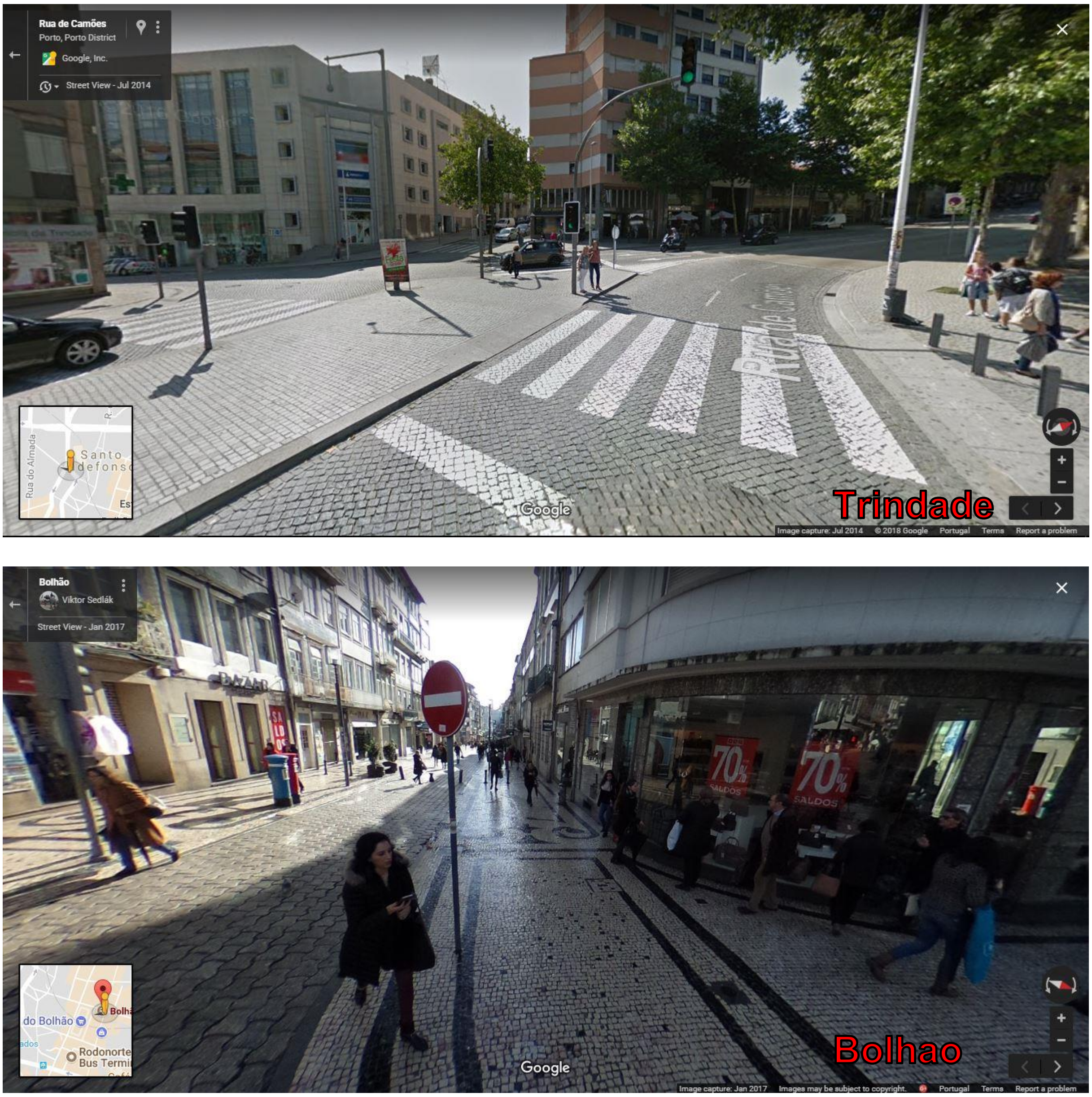


Fig .15- The surroundings of Trindade and Bolhao stations' areas. Source: Google.maps.

However, figure 16 shows that stations from Nasoni to Fanzeres hold the lowest node value, while the stations in the center of Porto have the highest. Figure 17 shows that Trindade, Bolhao, Campo 24 Agosto and Casa da Musica have the highest place value; stations from Estadio do Dragao to Fanzeres have very low values, while stations from Francos to Senhora da Hora with Heroismo, Lapa and Carolina Michaelis stations hold average place value. Figure 18 illustrates that accessibility is not related to the location of the station, in/away from Porto center. For instance: Levada station, which is outside Porto center, has higher pedshed ratio value than Trindade station, which is in the center of Porto. The closeness of a commercial center to Levada station has a direct impact on place and PedShed ratio values of the station.

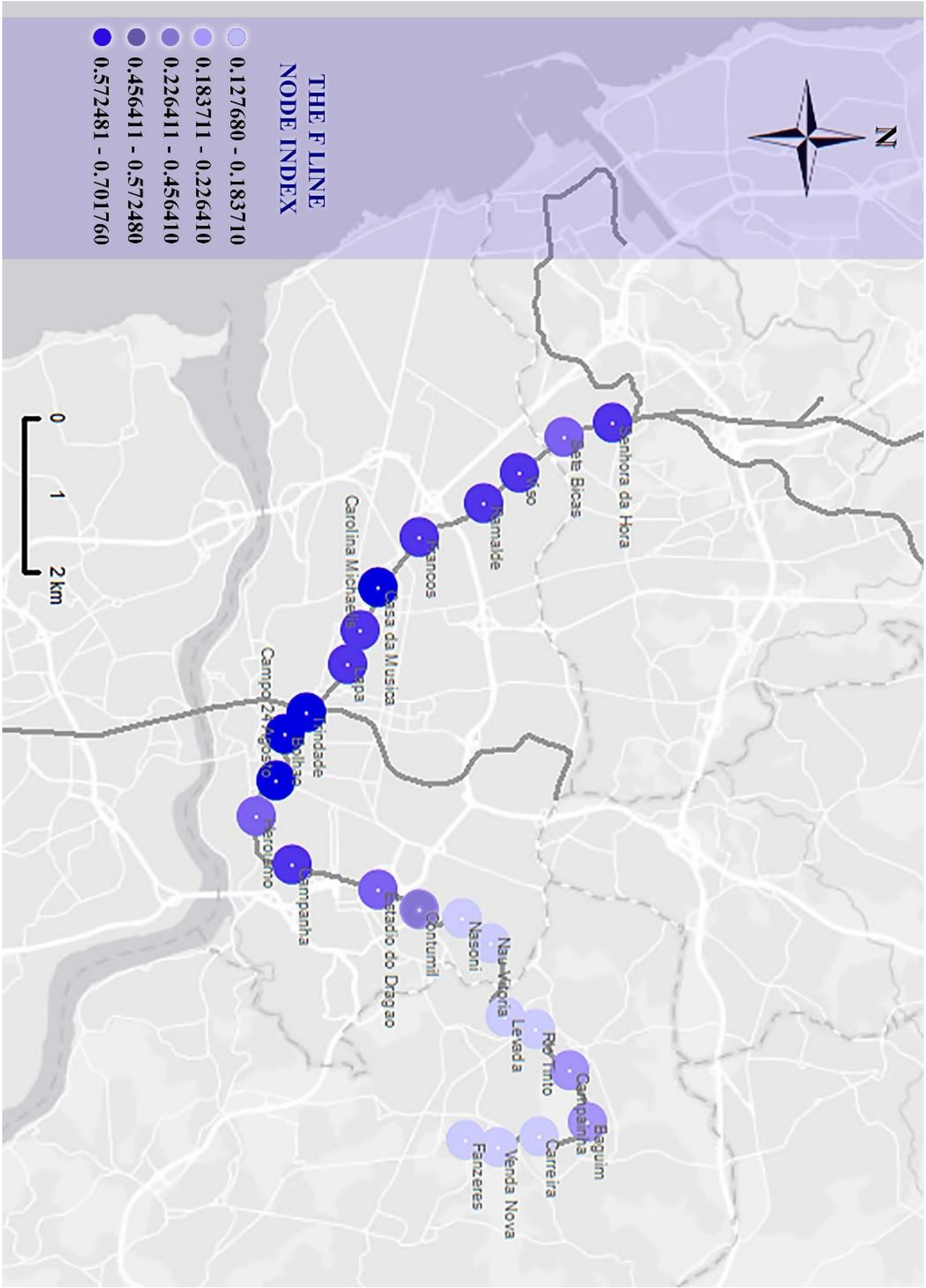


Fig .16- The node index of the F line stations

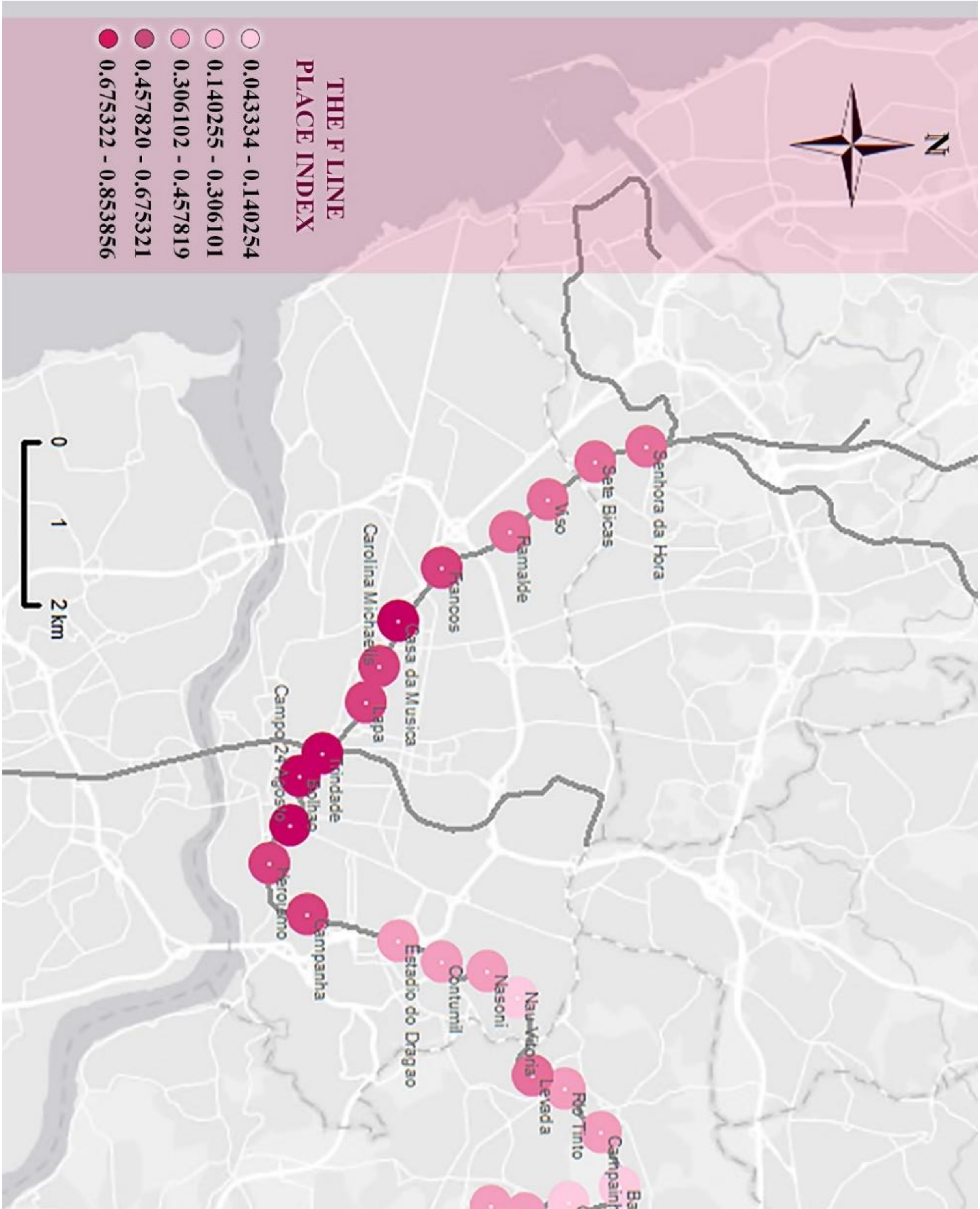


Fig .17- The place index of the F line stations

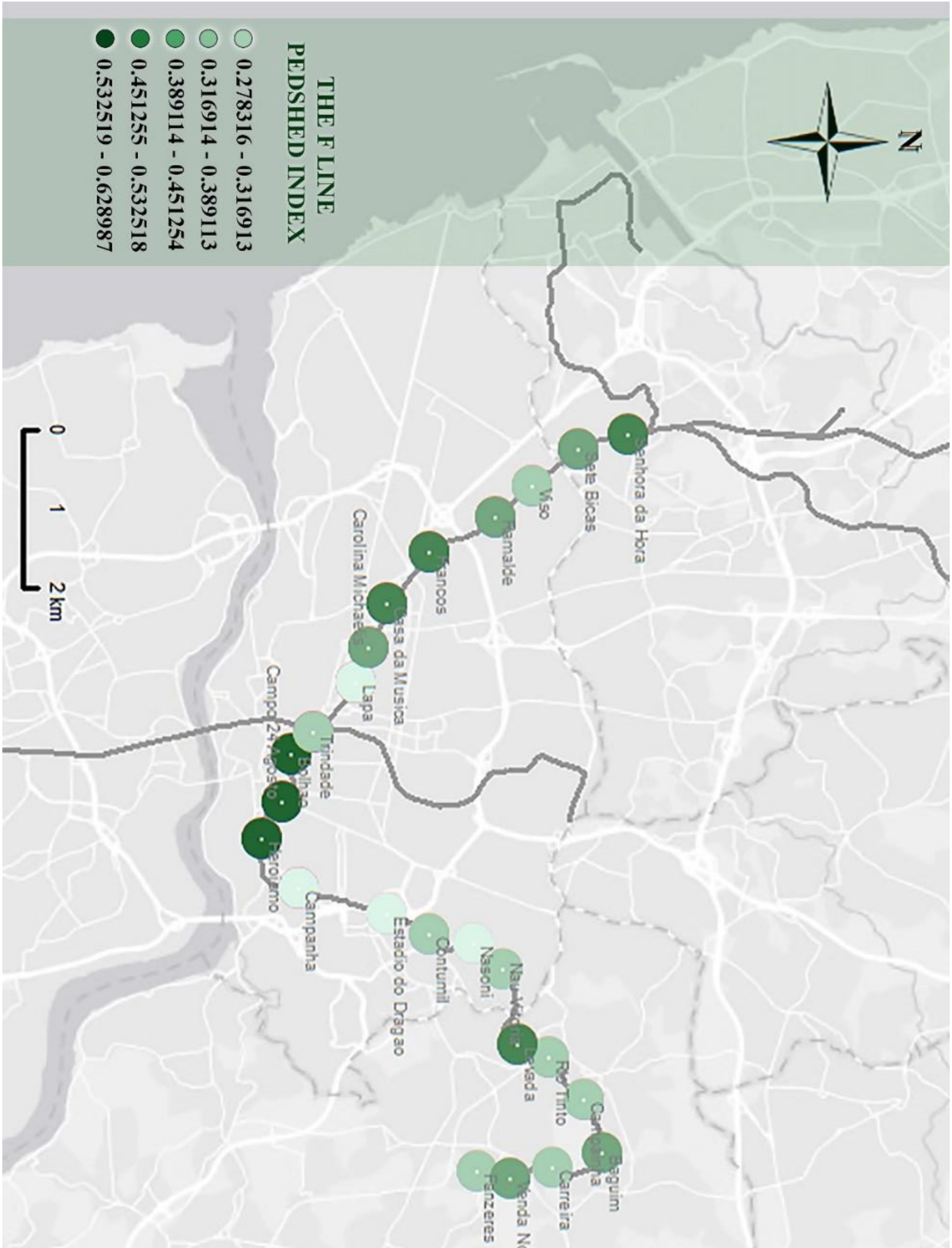


Fig .18- The PedShed index of the F line stations.

After calculating the node and place indexes, the stations are classified in accordence to node-place model into Stress, Balance, Dependence, Unbalanced node and Unbalanced place. However, since the node-place model does not have a threshold to distinguish between the five classifications. Therefore, based on the node-place model calculation for this research, it takes one unit to distinguish between balanced and unbalanced stations in terms of node and place values. For instance, a balance station like Franco shows no unit (0.10) differeance between its place (0.52) and node (0.53) values. On the other hand, unbalanced station like Heroismo has higher difference than 0.10 in place (0.57) and node (0.45) values. Thus, Heroismo is in unbalanced place zone. Figure 19 illustrates that Franco, Carolina Michaelis, Lapa, Sete Bicas and Ramalde stations are in the Balance zone, where their node and place values are convergent. In contrast, Bolhao, Trindade, Casa da Musica and Campo 24 Agosto station are in Stress zone, since they have the highest values in node and place. On the other hand, Campanha, Heroismo and Levada are in Unbalanced Place zone since their place values are higher than node values, unlike Viso, Senhora da Hora and Estadio do Dragao stations whose node values are higher than place values, hence their belonging to the Unbalanced Node zone. Further, Contumil, Campainha, Carreira, Baguim, Venda Nova, Fanzeres, Nasoni, Rio Tinto and Nau Vitoria stations are in Dependence zone since they have the lowest node and place values. Finally, it is clear that Levada station position can be considered in Dependence zone since its node value corresponds with the other stations’ located in Dependence zone. Yet, since its place value is 0.40, which is far higher than them, Levada station is then considered as unbalanced place.

Figure 20 shows that Levada station stands out from peripheral ones, which are the dependent stations, while the balanced stations are not necessarly located in the center, such as Sete Bicas.

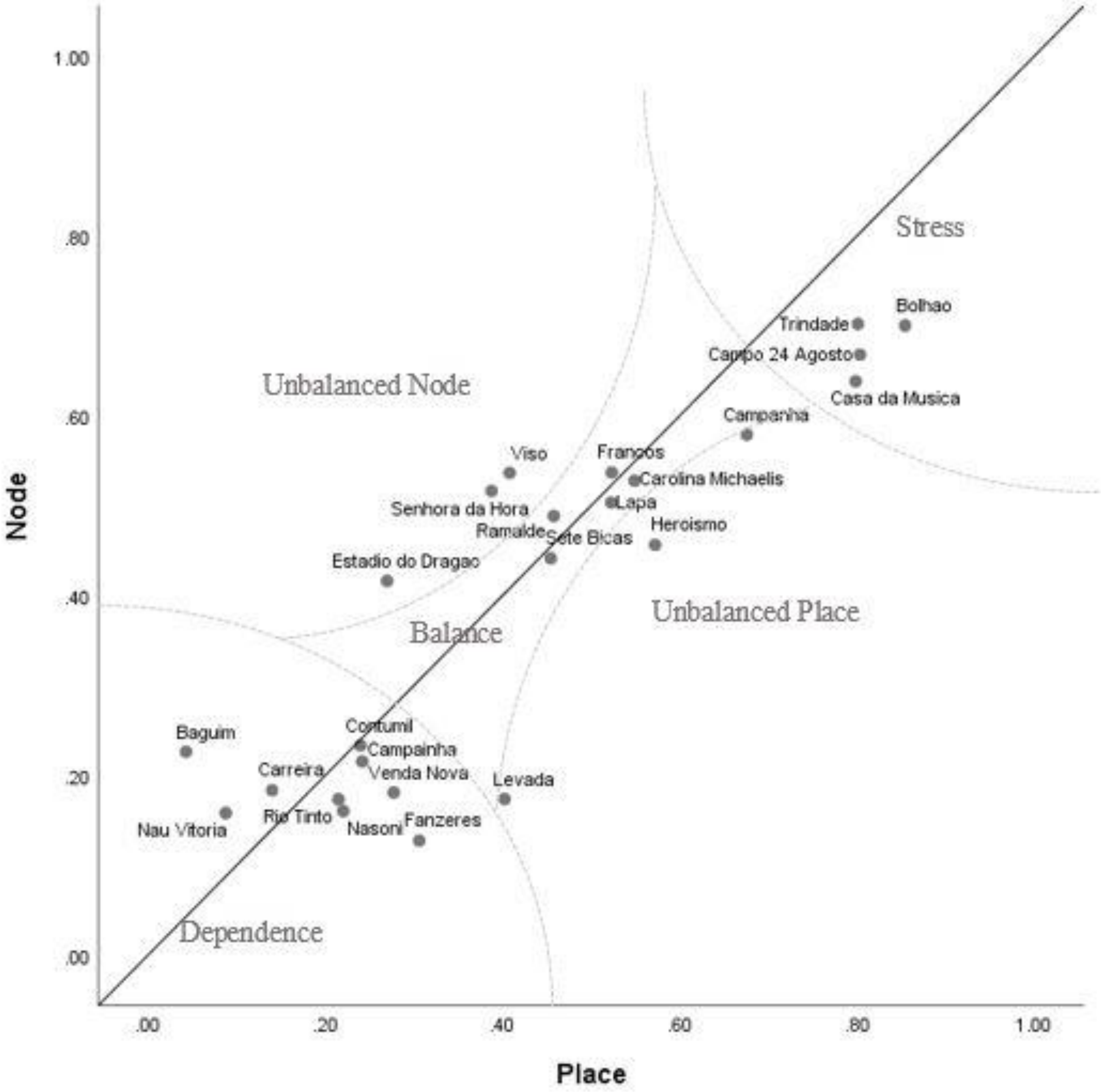


Fig. 19- Psitions of The F line metro stations in node-place model.

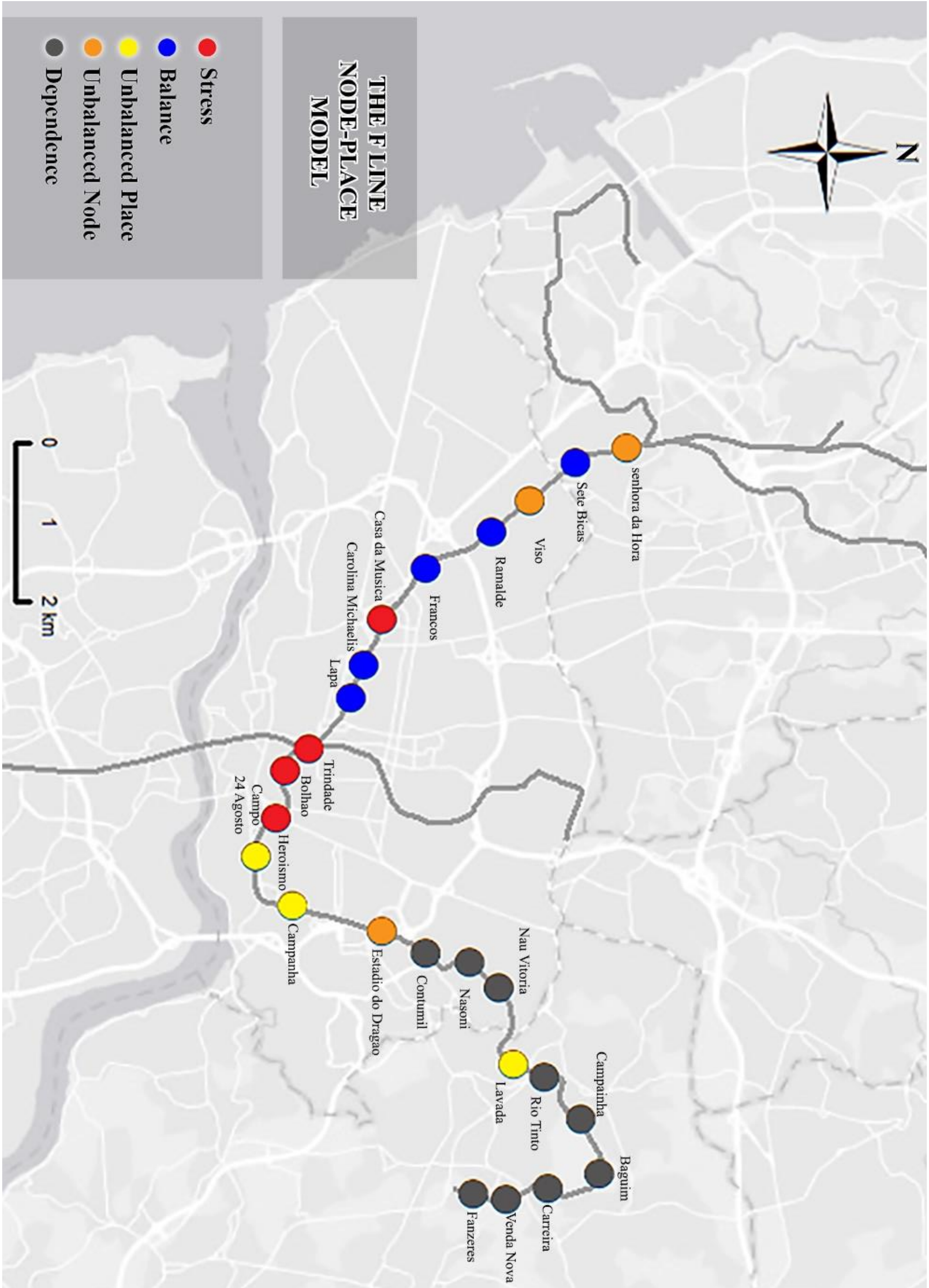


Fig. 20- The F line metro stations map in accordance to node-place model.

In order to classify the stations within the three dimantions: node, place and pedshed ratio, cluster analysis was made using two-step analysis method with Euclidean distance measure via SPSS software (Hair et al. 2010). Three clusters were the optimal choice, but when trying to see the option of four clusters, Levada station was considered as a cluster itself by comparing between "a" and "b", where "a" refers to a three clusters' chosen group and "b" refers to a four clusters' group. In group "a", Levada station is in the cluster number 3 where the node, place and PedShed ratio mean values are low whereas, in group "b", cluster number 3 contains only the aforementioned station (Fig .21).

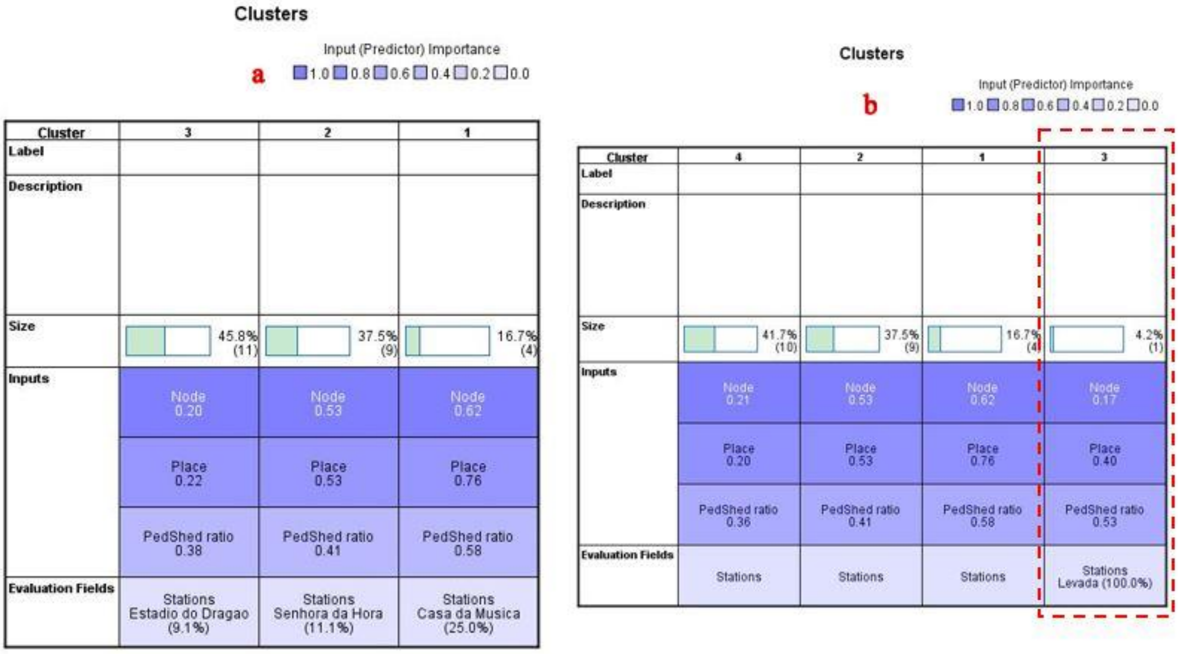


Fig .21- The "a" and "b" clusters groups. The cluster (3) in "b" holds only Levada station, while all the other clusters have almost the same results with "a".

Therefore, the cluster analysis was done by classifying the stations in three clusters (see fig .22 and table 5):

- cluster 1 contains 4 stations that have high node, place and PedShed ratio;
- cluster 2 contains 9 stations that have average node, place and PedShed ratio;
- cluster 3 contains 11 stations that have low node, place and PedShed ratio.

The F statistics in SPSS revealed that the node index further allows to identify the cluster classification (F= 60.6), followed by place index (F= 35.9), only that PedShed has the lowest impact on identifying clusters (F=13.8) meaning that most of the stations do not differ greatly in terms of pedestrian accessibility.

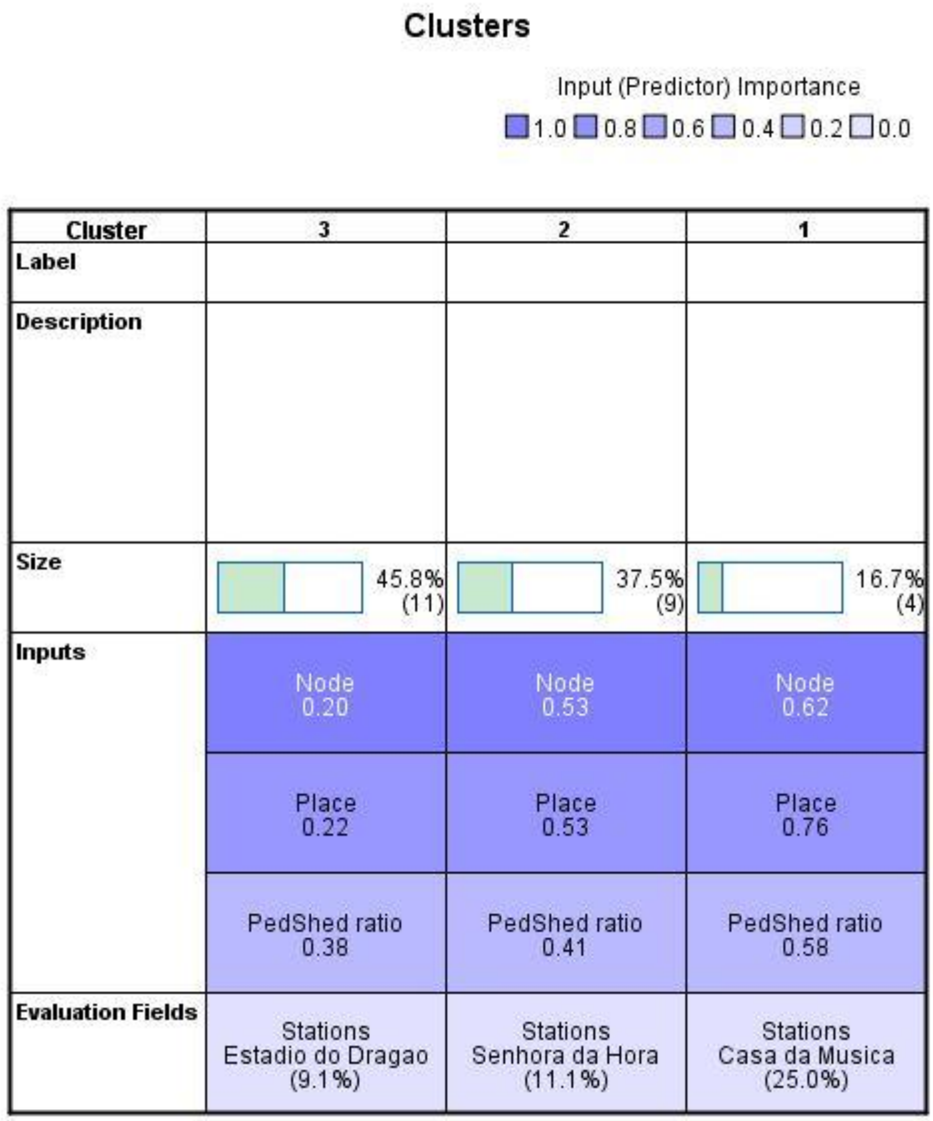


Fig .22- The node, place and PedShed ratio mean values in every cluster and the station that represent every cluster.

Table 5- The stations in every cluster.

Cluster 1	Cluster 2	Cluster 3
Bolhao	Trindade	Estadio do Dragao
Campo 24 Agosto	Campanha	Levada
Heroismo	Carolina Michaelis	Contumil
Casa da Musica	Francos	Campainha
	Lapa	Carreira
	Ramalde	Baguim
	Viso	Venda Nova
	Senhora da Hora	Fanzeres

Cluster 1	Cluster 2	Cluster 3
	Sete Bicas	Nasoni
		Nau Vitoria
		Rio Tinto

Discussing the Results

After adding PedShed ratio in classification process via cluster analysis, the station labels start to be different (fig .23). For instance, it is obvious that Trindade station in node-place model is in Stress zone where node and place are maximum (see fig .19). Yet, in cluster classification, Trindade station is in cluster 2 where node, place, and PedShed ratio are average (see fig .23). Similarly, in node-place model, Estadio do Dragao station is in Unbalanced node where node index is high and place index is low. However, according to cluster analysis, the station is in cluster 3, where node, place, and PedShed indexes are low. Likewise, Heroismo station in node-place model is in Unbalanced place but after clustering, the station turns out to be in cluster 1 where node, place, and PedShed indexes are high. Also, in node-place model, Viso station is classified as unbalanced node although its place index (0.40) is closer to the highest place value (0.85) than the lowest one (0.04). However, after including PedShed ratio index to the classification process via cluster analysis, the Viso station is in cluster 2 where node, place, and PedShed ratio are average. Thus, PedShed ratio index influences the classification process once it was included. Furthermore, according to cluster analysis, there is no difference between the stations that are close to the middle diagonal line or the stations that are far from it.

As a result, cluster analysis reveals that the stations, which have low node, low place and low PedShed indexes in cluster 3, are isolated with poor transit system and weak urban activities resulting in car dependent areas, therefore, they are considered as Non TODs. However, increasing the place and node indexes by attracting urban development and increasing the transport supply, the areas could reach a typical TOD. Therefore, the aforementioned cluster is labeled as “Future TODs” according to Vale (2015), while cluster 1 is categorized as “Urban TODs” (Vale, 2015), which has stations that have high PedShed, place, and node indexes, thereby their suitability for pedestrians as walking accessibility is high and they are considered friendly-pedestrian TODs. As for the stations in cluster 2, their node and place values are balanced with a PedShed that is lower than the one in Urban TODs, hence, their label as “Urban less friendly-pedestrian TODs” (fig .24).

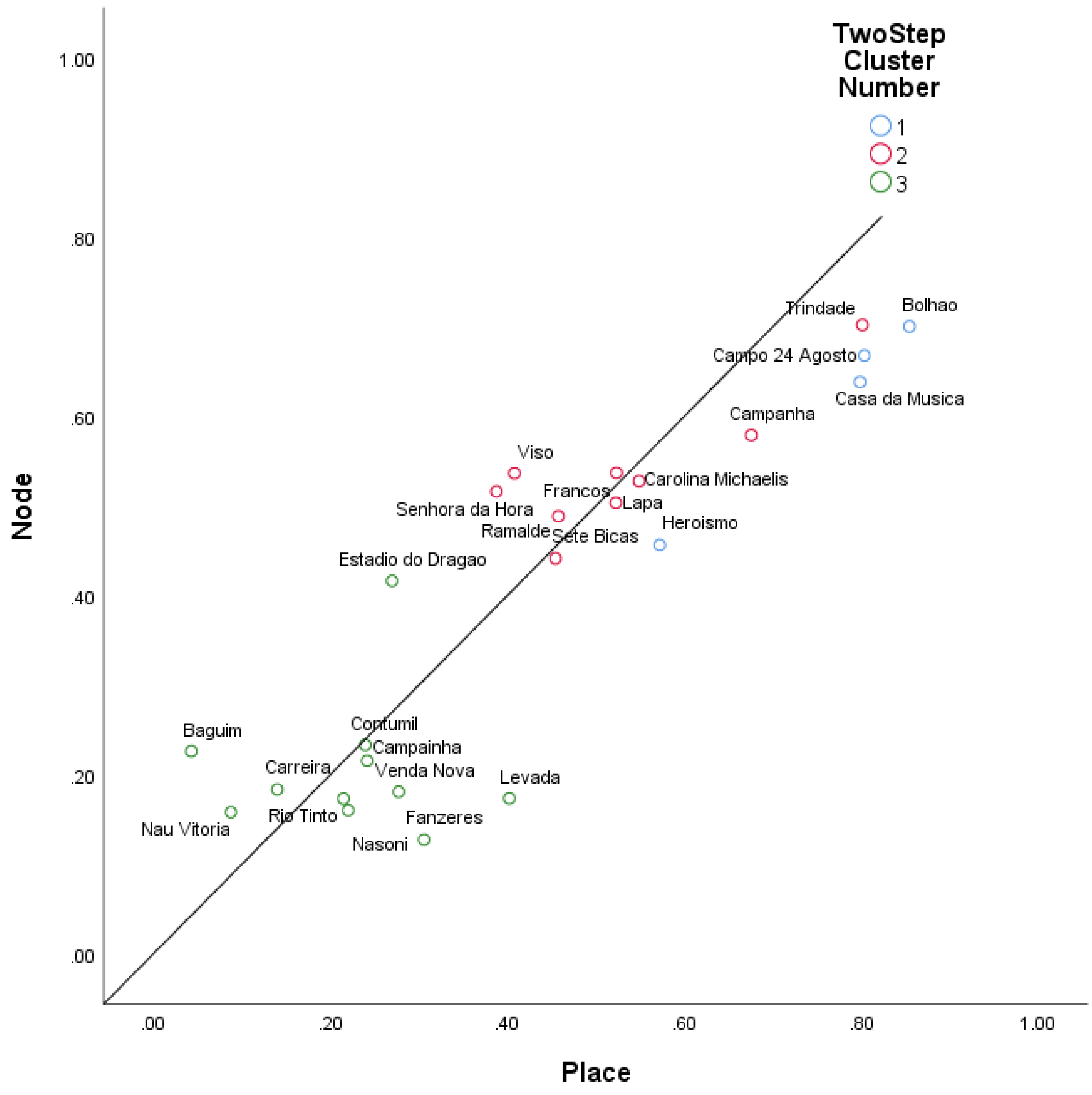


Fig .23- The clusters of node-place areas for the F line of Porto metro.

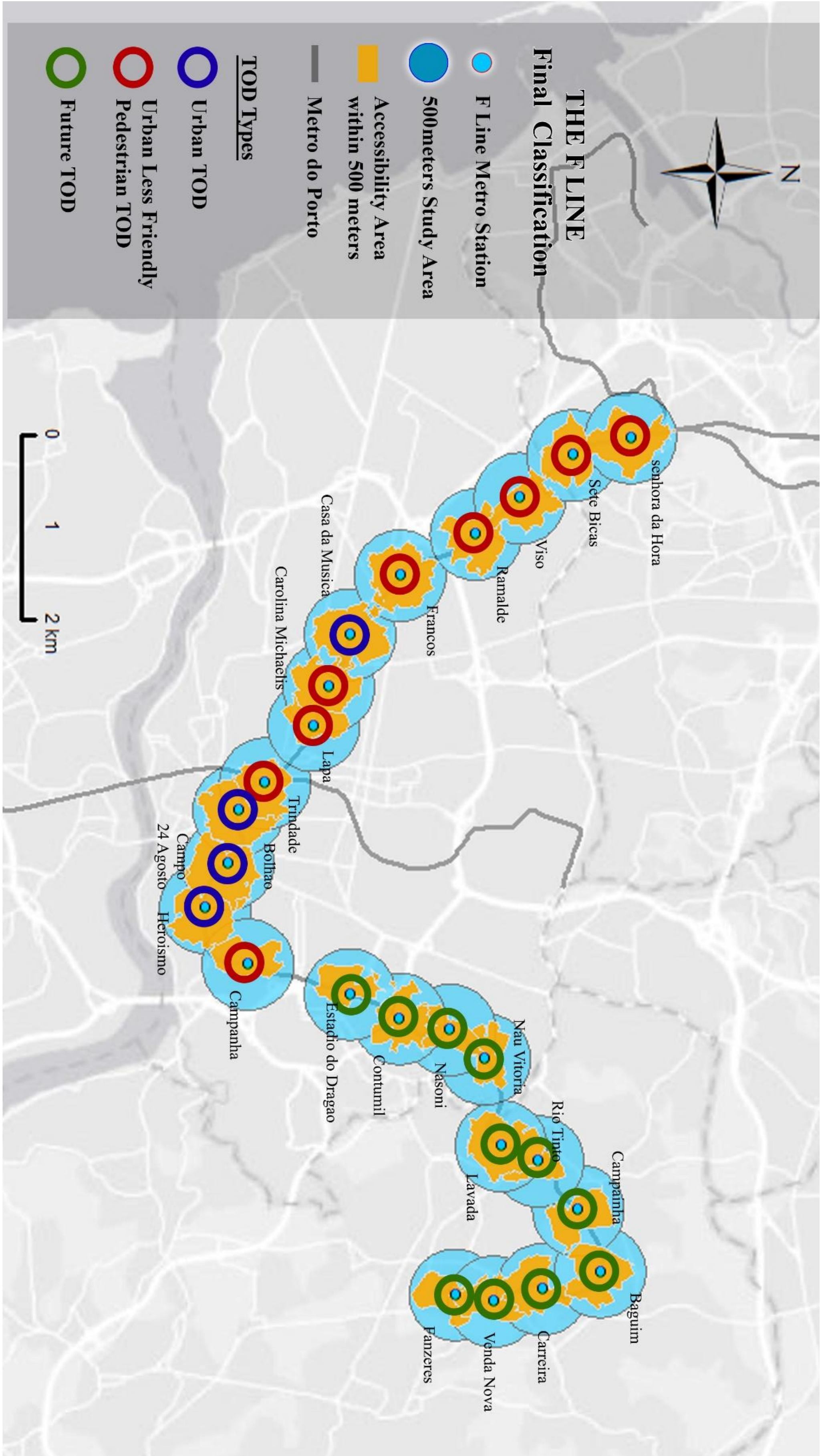


Fig .24- Final classification of the F line metro stations

6 CONCLUSION

The previous results show that 11 stations out of 24 are in "Future TODs" group, which means that almost half of F metro line stations have good potentials to become "Urban TODs" by enhancing their transit services and supplies and by providing their areas with more mixed uses. As a result, walkability will increase in the areas, especially by giving more attention towards the built environment that helps in increasing the pedestrian accessibility. Thus, cluster analysis is a good procedure to determine the impact of evaluating the walkability features. However, cluster analysis results are not enough to know the necessary measures to turn each station to an urban TOD. For instance, Levada station is classified as a future TOD, when in node-place model results it has a high place value. Therefore, increasing the transit services in Levada area is enough to achieve urban TOD. That is why in Vale study (2015), the group that has high PedShed and place with low node was classified as "Under supplied transit TOD". Therefore, if the rest of Porto metro lines is included for future researches, the clusters numbers will increase, resulting in more classifications for Porto metro line stations.

Through the study, the node-place model appeared to be simple and quick when taking a general idea of station classification. However, as the results show, the model is not enough in practical classification, for, despite measuring the correlation between the transit and urban development, it does not clarify the degree of this the correlation that can be shown by evaluating the walkability (Lyu et al., 2016). For instance, the place index of an area can be high as well as the node index, but the built environment, such as building distribution and street network linkage, does not help in orienting the attraction towards the station.

However, in this study, if the calculations are extended to measure built environment or the design, not just the PedShed ratio, the results could appear differently.

REFERENCES

Bertolini, L. (1999). *Spatial Development Patterns and Public Transport: The Application of an Analytical Model in the Netherlands.* Planning Practice & Research.

Bertolini, L. (2008). *Station areas as nodes and places in urban networks: an analytical tool and alternative development strategies.* In: Bruinsma, F., Pels, E., Priemus, H., Rietveld, P., Van Wee, B. (Eds.), Railway Development: Impacts on Urban Dynamics. Physica-Verlag Heidelberg, Leipzig, pp. 35–57.

Carlton, Ian. (2007). *Histories of Transit-Oriented Development: Perspectives on the Development of the TOD Concept*. Institute of Urban and Regional Development University of California, Berkeley.

Chorus, B., Bertolini, L. (2011). *An application of the node place model to explore the spatial development dynamics of station areas in Tokyo.* J. Transp. Land Use.

Comboios de Portugal, CP (https://www.cp.pt). 07/02/2018.

Cramer, D., Howitt, D. (2004). *The SAGE dictionary of statistics*. London: SAGE.

Fernandes, A. (2011). *Transit-Oriented Development – um ensaio metodológico para o Porto.* Master in Geography at Faculdade de Letras, Universidade do Porto.

Hair, J., Black, W., Babin, B., Anderson, R. (2010). *Multivariate data analysis*. Seventh edition. Pearson Education Limited.

Haseeb, SH. (2017). *Satellite cities of the twentieth century: At sustainability analysis of Milton Keynes and Reston.* Master of Science in Urban Planning at the School of Architecture, Planning and Preservation at Columbia University in the City of New York.

Instituto Nacional de Estatística, Statistics Portugal. (http://www.ine.pt/). 03/02/2018.

Instituto Nacional de Estatística, I.P. (2007). *Classificação Portuguesa das Actividades Económicas Rev.3.* Statistics Portugal. (http://www.ine.pt/). 13/02/2018.

Jacobson, J., Forsyth, A. (2008). *Seven American TODs: Good practices for urban design in Transit-Oriented Development projects.* J. Transp. Land Use.

Jain Singh, Y., Fard, P., Zuidgeest, M., Brussel, M., van Maarseveen, M. (2014). *Measuring transit oriented development: a spatial multi criteria assessment approach for the City Region Arnhem and Nijmegen.* J. Transp. Geogr.

Jornalismo Porto Net (https://jpn.up.pt/). 03/02/2018.

Kamruzzaman, Md., Baker, D., Washington, S., Turrell, G. (2014). *Advance transit oriented development typology: case study in Brisbane, Australia.* J. Transp. Geogr.

Lyu, G., Bertolini, L., Pfeffer, K. (2016). *Developing a TOD typology for Beijing metro station areas.* J. Transp. Geogr.

Metro do Porto, SA (https://en.metrodoporto.pt/). 02/02/2018.

Metro do Porto. (2011). Annual report.

Papa, E., Bertolini, L. (2015). *Accessibility and Transit-Oriented Development in European metropolitan areas.* J. Transp. Geogr.

Park, S., Choi, K., Seung Lee, J. (2015). *To walk or not to walk: Testing the effect of path walkability on transit users' access mode choices to the station.* J. Sustainable Transportation.

Pinho, P., Silva, C., Moura, F., Amante, A.T., Altier, M. (2017). *Avaliação da Procura Estrutural das linhas alternativas para expansão da Rede do Metro do Porto*. Relatório MP3 Versao Final.

PricewaterhouseCoopers (https://www.pwc.com/). 21/11/2017.

Renne, J.L. (2009). *From transit-adjacent to transit-oriented development.* Local Environment.

Reusser, D.E., Loukopoulos, P., Stauffacher, M., Scholz, R.W. (2008). *Classifying railway stations for sustainable transitions – balancing node and place functions.* J. Transp. Geogr.

Schlossberg, M., Brown, N. (2004). *Comparing Transit Oriented Developments Based on Walkability Indicators.* J. Transportation Research Board.

Sociedade de Transportes Colectivos do Porto, STCP, SA (http://www.stcp.pt). 05/02/2018.

Urban Land Institute (https://uli.org/). 21/11/2017.

Vale, D.S., (2015). *Transit-oriented development, integration of land use and transport, and pedestrian accessibility: Combining node-place model with pedestrian shed ratio to evaluate and classify station areas in Lisbon.* J. Transp. Geogr.

Vale, D.S, Viana C.M, Pereira, M. (2018). *The extended node-place model at the local scale: Evaluating the integration of land use and transport for Lisbon's subway network*. J. Transp. Geogr.

ANNEX

A1 – The data of node index variables for the F line stations.
A2 – The data of place index variables for the F line stations.

A1 –The data of node index variables for the F line stations.

Stations	y1	LG y1	y2	y2 rescale	y3	y3 rescale	y4	SQR y4	SQR y4 rescale	y5	SQR y5	SQR y5 rescale	y6	y6 rescale	y7	y7 rescale
Senhora da Hora	7	0.8	691	0.619048	50	0.97561	8	2.83	0.368489583	150	12.25	0.30771163	2000	0.42446	102	0.117783
Sete Bicas	8	0.9	771	0.700101	49	0.95122	2	1.41	0.18359375	46	6.78	0.170308968	1000	0.184652	0	0
Viso	8	0.9	771	0.700101	51	1	12	3.46	0.450520833	222	14.9	0.37427782	1600	0.328537	0	0
Ramalde	8	0.9	771	0.700101	49	0.95122	4	2	0.260416667	103	10.15	0.254961065	1700	0.352518	0	0
Francos	8	0.9	771	0.700101	46	0.878049	24	4.9	0.638020833	384	19.6	0.492338608	850	0.148681	0	0
Casa da Musica	8	0.9	771	0.700101	44	0.829268	50	7.07	0.920572917	1046	32.34	0.812358704	1500	0.304556	0	0
Carolina Michaelis	8	0.9	771	0.700101	43	0.804878	12	3.46	0.450520833	240	15.49	0.389098217	2100	0.448441	0	0
Lapa	8	0.9	771	0.700101	40	0.731707	6	2.45	0.319010417	124	11.14	0.279829189	2700	0.592326	0	0
Trindade	10	1	1067	1	41	0.756098	52	7.21	0.938802083	770	27.75	0.69706104	2400	0.520384	0	0
Bolhao	8	0.9	731	0.659574	41	0.756098	50	7.07	0.920572917	1585	39.81	1	3000	0.664269	0	0
Campo 24 Agosto	8	0.9	731	0.659574	38	0.682927	59	7.68	1	1315	36.26	0.910826426	2400	0.520384	0	0
Heroismo	8	0.9	731	0.659574	37	0.658537	8	2.83	0.368489583	253	15.91	0.39964833	1100	0.208633	0	0
Campanha	7	0.85	652	0.579534	37	0.658537	38	6.16	0.802083333	754	27.46	0.689776438	2200	0.472422	0	0
Estadio do Dragao	5	0.7	362	0.285714	36	0.634146	8	2.83	0.368489583	185	13.6	0.341622708	230	0	866	1
Contumil	2	0.3	159	0.080041	32	0.536585	16	4	0.520833333	345	14.07	0.353428787	550	0.076739	0	0
Nasoni	2	0.3	159	0.080041	28	0.439024	0	0	0	0	0	0	1500	0.304556	0	0
Nau Vitoria	2	0.3	159	0.080041	27	0.414634	0	0	0	0	0	0	2200	0.472422	0	0
Levada	2	0.3	159	0.080041	22	0.292683	0	0	0	0	0	0	2500	0.544365	0	0
Rio Tinto	2	0.3	159	0.080041	17	0.170732	0	0	0	0	0	0	3000	0.664269	0	0
Campainha	2	0.3	159	0.080041	15	0.121951	0	0	0	0	0	0	4000	0.904077	90	0.103926
Baguim	2	0.3	160	0.081054	14	0.097561	0	0	0	0	0	0	4400	1	92	0.106236
carreira	2	0.3	160	0.081054	12	0.04878	0	0	0	0	0	0	3800	0.856115	0	0
venda Nova	2	0.3	160	0.081054	10	0	0	0	0	0	0	0	3600	0.808153	68	0.078522
Fanzeres	1	0	80	0	10	0	0	0	0	0	0	0	3100	0.688249	178	0.205543

A2 – The data of place index variables for the F line stations.

Stations	x1	x1 rescale	x2	LG x2	LG x2 rescale	x3	SQR x3	SQR x3 rescale	x4	LG x4	LG x4 rescale	x5	x5 rescale	x6	x6 rescale
Senhora da Hora	7121	1	138	2.14	0.52739726	116	10.77	0.389370933	5	0.7	0.185185185	80	0.2241888	0.9	0
Sete Bicas	2756	0.279108	3287	3.52	1	552	23.49	0.849240781	25	1.4	0.37037037	81	0.2271386	0.9	0
Viso	3956	0.477291	132	2.12	0.520547945	59	7.68	0.277657267	584	2.77	0.732804233	153	0.439528	0.9	0
Ramalde	4459	0.560363	125	2.1	0.51369863	39	6.24	0.225596529	286	2.46	0.650793651	274	0.7964602	0.9	0
Francos	6416	0.883567	978	2.99	0.818493151	273	16.52	0.59725235	291	2.46	0.650793651	68	0.1887906	0.9	0
Casa da Musica	5317	0.702064	791	2.9	0.787671233	695	26.36	0.953000723	2355	3.37	0.891534392	271	0.7876106	0.91	0.6666667
Carolina Michaelis	6077	0.827581	279	2.45	0.633561644	462	21.49	0.776934201	1378	3.14	0.830687831	80	0.2241888	0.9	0
Lapa	5972	0.810239	291	2.46	0.636986301	189	13.75	0.497107737	1371	3.14	0.830687831	126	0.359882	0.9	0
Trindade	4938	0.639472	1667	3.22	0.897260274	765	27.66	1	3498	3.54	0.936507937	229	0.6637168	0.91	0.6666667
Bolhao	4889	0.631379	2925	3.47	0.982876712	763	27.62	0.998553868	6019	3.78	1	290	0.8436578	0.91	0.6666667
Campo 24 Agosto	6716	0.933113	678	2.83	0.76369863	374	19.34	0.699204628	3198	3.5	0.925925926	285	0.8289086	0.91	0.6666667
Heroismo	4993	0.648555	302	2.48	0.643835616	123	11.09	0.400939986	482	2.68	0.708994709	127	0.3628319	0.91	0.6666667
Campanha	3572	0.413873	146	2.16	0.534246575	124	11.14	0.40274765	443	2.65	0.701058201	343	1	0.915	1
Estadio do Dragao	3063	0.32981	516	2.71	0.72260274	59	7.68	0.277657267	75	1.88	0.497354497	25	0.0619469	0.9	0
Contumil	4200	0.517589	69	1.84	0.424657534	9	3	0.10845987	21	1.32	0.349206349	17	0.0383481	0.9	0
Nasoni	3294	0.36796	24	1.38	0.267123288	6	2.45	0.08857556	0		0	207	0.5988201	0.9	0
Nau Vitoria	1066	0	6	0.78	0.061643836	0	0	0	0		0	192	0.5545723	0.9	0
Levada	4912	0.635178	1940	3.29	0.921232877	16	4	0.14461316	75	1.88	0.497354497	77	0.2153392	0.9	0
Rio Tinto	3834	0.457143	71	1.85	0.428082192	70	8.37	0.302603037	1	0	0	39	0.1032448	0.9	0
Campainha	4116	0.503716	73	1.86	0.431506849	104	10.2	0.368763557	2	0.3	0.079365079	27	0.0678466	0.9	0
Baguim	2104	0.171429	4	0.6	0	6	2.45	0.08857556	0		0	4	0	0.9	0
carreira	3622	0.42213	14	1.15	0.188356164	4	2	0.07230658	4	0.6	0.158730159	4	0	0.9	0
venda Nova	4418	0.553592	97	1.99	0.476027397	32	5.66	0.204627621	2	0.3	0.079365079	123	0.3510324	0.9	0
Fanzeres	3033	0.324855	258	2.41	0.619863013	33	5.74	0.207519884	0		0	236	0.6843658	0.9	0