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Classifying European railway stations: a review

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ABSTRACT

Railway stations play a key role in sustainable mobility transitions. They not only provide transport infrastructure, but also serve as hubs of social and economic activity – often centrally located and tightly integrated into the urban fabric of their catchment areas. Station classification has emerged as a tool to support the development of these areas, particularly in the context of sustainable land-use and transport policy integration, and Transit-Oriented Development (TOD). Over the years, a wide variety of classification approaches have been developed. However, despite the growing importance of rail travel and TOD at the European level, no uniform approach to classifying railway stations currently exists. To address this gap, we conducted a systematic literature review of European station classification studies. Of the 1,675 studies screened, 31 met our eligibility criteria and were analysed in depth. We examined the similarities and differences as well as rationales among the classification approaches identified, focusing on (i) general characteristics like objectives and catchment areas (ii) the classification criteria used and (iii) the resulting classes. Even though we found a wide variety both for criteria and classes, we were able to identify recurrent emergent themes that can help developing a unified European classification framework. We conclude with an outline of policy changes necessary to achieve such a framework. Our analysis presents a first step toward a more standardised and inclusive approach to station classification, helping to define shared station (area) transformation pathways and engage diverse stakeholder groups in shaping a more sustainable future in Europe and beyond.

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Railway; station; classification; node-place; review; train

1. Introduction and theoretical background

It is commonly understood that the transport sector is one of the most significant sources of anthropogenic greenhouse gas emissions (Ülengin et al., 2018), thus indubitably contributing to the climate emergency. Rail transport holds a significant role in everyday mobility for the shift to more sustainable transport systems, not only by releasing far

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fewer air pollutants than private cars per passenger – or tonne-kilometer (International Energy Agency, 2019), but also by reducing the physical artificial space allocated to mobility, thus producing positive environmental externalities (Drut, 2018; Reusser et al., 2008). However, in most European regions, rail transport is still not able to fully compete with the perceived benefits of private motorised transport (Grotenhuis et al., 2007) like perceived comfort and perceived reduced travel time (Beirão & Sarsfield Cabral, 2007).

The challenges and potentials of station area development have led to the topic being part of recent EU transport and urban policies. Under the proposed revision of the TEN-T Regulation (COM/2021/812 final; European Commission, 2021), all designated urban nodes – often centred around major railway stations – are expected to adopt Sustainable Urban Mobility Plans (SUMPs) that integrate land use and mobility planning across their functional urban areas. This approach is further supported by Commission Recommendation (EU) 2023/550 (European Commission, 2023), which encourages Member States to promote and fund such integrated planning. This reflects a shift toward more compact, multimodal, and accessible station-area development aligned with EU climate, accessibility, and modal shift goals. Furthermore, recent EU research projects such as SMART MR Interreg (c.f. Nared et al., 2020) or RAIL4CITIES (European Commission, 2025) have concentrated on the sustainable development of European stations and catchment areas.

The shift toward more sustainable transport modes has a significant urban dimension, especially in Europe, with its unique density and rail transport history. For rail transport to become a more attractive everyday option here, the integration of railway stations within their urban surroundings is crucial, as stations typically occupy a unique position, linking transport networks and physical urban spaces (Lunardon et al., 2023; Pucci, 2019). However, this is a complex task (Bertolini, 2008), as it places stations between transport and urban agendas, resulting in fragmented responsibilities and limited policy attention (Lunardon et al., 2023).

Against this backdrop, station classification is suggested by many authors as an instrument to support planners and decision-makers, mainly in order to (i) improve accessibility (Pucci, 2019) and quality of the services in stations (Havlena et al., 2014), (ii) identify comparable stations with respect to certain questions, thus reducing management complexity and enabling the identification of sites and actors with comparable challenges or experiences (Zemp et al., 2011a), (iii) delineate the most suitable station areas for the settlements of new activities (Papa et al., 2013) or (iv) assist policy prescription on a strategic level (Caset et al., 2018). Accordingly, the idea of classifying railway stations is not new, per se – in fact, the Node-Place (NP) model (Bertolini, 1999) was the first and to date most influential approach to quantitative station classification, which is why the model and its limitations are described in detail in the following:

The model expresses the duality of the station as an interface between the transport network and its spatial surroundings as "part of a system of both competing and complementary nodes and places" (Bertolini, 1999, p. 201) striving for balance. The NP model is based on the interplay of network accessibility and land use, using parameters such as accessibility by train, public transport, car and bicycle for the transport function of the node, and the number of residents and degree of functional mix for the urban function of the place (Bertolini, 1999).

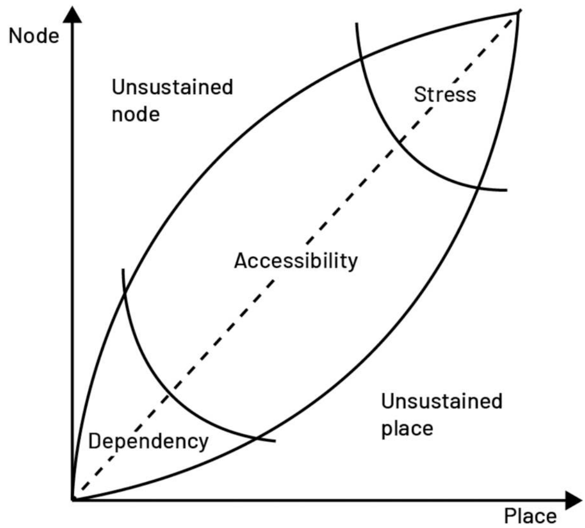

Figure 1. Node-place model. Figure adapted from Bertolini (1999).

The original model takes the form of a simple XY diagram (Figure 1). The Y-axis represents the node value of a location, corresponding to its accessibility and, consequently, its potential for physical human interaction – the more accessible a place is, the greater the number of people who can reach it. The X-axis reflects the place value, indicating the intensity and diversity of activities present, and thus the extent to which this interaction potential is actually realised. Areas classified along the middle diagonal axis can be considered balanced (where the node and the place are equally strong), whereas areas towards the edges of the diagram are considered unbalanced. Through this graphic representation, four different situations can emerge (c.f. Figure 1). Unbalanced locations characterised by high accessibility but limited land-use intensity are referred to as "unsustained nodes," whereas those with substantial land-use activity but insufficient transport connectivity are termed "unsustained places". Areas that have high node and place values, meaning intense transportation flows and a high diversity of urban activities, are marked "under stress", whereas areas with low node and place values are characterised as "dependent". Ideally, a location should combine strong network centrality with a high concentration of urban functions (Bertolini, 1999).

The NP model is widely used to assess the degree of TOD in urban transport systems and their catchment areas "through a combination of indicators of both transit development and land use" (Zheng & Austwick, 2023, p. 1). However, its limited set of indicators has led researchers to propose additional parameters, such as sustainability judgements (Reusser et al., 2008), urban design features of station areas (Vale, 2015), or the functional and morphological interrelations between transport and urban form (Lyu et al., 2016). Reflecting on its relevance for TOD around railway stations, Vale (2015) also notes the model does not "allow evaluating if the balanced node-place site is a TOD or simply a TAD [transit-adjacent development]" (p. 71). Therefore, since the model's introduction in the late 1990s, many authors have proposed variations and additions (e.g. Vale, 2015; Zheng & Austwick, 2023) to better capture station characteristics and regional contexts or specific objectives and planning aims (Nigro et al., 2019; Zheng & Austwick, 2023), often resulting in substantial methodological divergence from the original NP model among others in terms of indicator selection (Eichhorn et al., 2021), data sources (Vale, 2015), classes (Zheng & Austwick, 2023) and scaling (Nigro et al., 2019), limiting the comparability of results across studies and regions. Moreover, many of these adaptations are developed without systematically integrating or consolidating existing classification approaches, further contributing to conceptual fragmentation. As a result, current approaches lack the generalizability required for broader, cross-national application, within a European-wide framework aligned with EU transport and spatial development policies. This limitation results in the need for a systematic, comprehensive literature review of station classification methods – including all published adaptations of the NP model as well as further approaches available – to identify and synthesise relevant parameters (Snyder, 2019) of the existing approaches (and not only look at compilations of classification indicators in the context of Transit-Oriented Development, Lyu et al., 2016, or the NP model, Pucci, 2019). Such a review can provide a solid foundation for developing an overarching classification system applicable across European countries while at the same time allowing for adaptations to the needs of specific regions, which could help comparing stations and understanding their local differences, supporting sustainable station area development, and aligning with the goals of EU policies (e.g. TEN-T Regulation, European Commission, 2021). In a next step, such a review can then act as a basis for the development of new classification approaches (see Pucci, 2019; or Vale, 2015, for examples of review-based development of new approaches). In this vein, this paper aims to (i) review in detail the different approaches that classify European railway stations and their surrounding areas, thus examining, among others, the criteria, classes, catchment areas, goals, and case studies of these approaches, and (ii) group the different classification criteria and classes into emergent themes according to their nature, thus providing an overview of the different requirements, needs, characteristics, and fields of action upon which future sustainable transformation pathways for railway stations and their surrounding areas can be drawn. After briefly describing the theoretical background and relevance of the subject in the present Section 1 of this paper, Section 2, aims at communicating the methods used for the literature review in detail. Section 3 provides the results of the review process and Section 4 critically discusses the results and provides a conclusion.

2. Methods

We conducted a systematic literature review of all available railway station classification studies originating from the European context. First, the keywords for the search were defined. Since our objective was to support European transport and spatial development policies, and since the review was conducted within the RAIL4CITIES project, which focuses on the European context, the search prompt aimed at identifying classification approaches originating from Europe (meaning also: classification systems whose applicability had been proposed for/tested in the European context, e.g. through a case study). Though it could be argued that the development of a classification system is detached from its initial case study context, during the screening it became apparent that the location where the system had been applied/tested highly influenced the methodology itself. Furthermore, only literature referring to passenger stations was considered eligible, meaning that publications about freight transport were excluded, since there is hardly any comparability between the criteria and spatial situations of the two station types. However, the type of passenger train station and its spatial layout played no role in the eligibility of the publications. For example, since there is often no clear division between overground and underground railway infrastructure (meaning that the same railway lines can change from over to underground and vice versa due to spatial conditions, stopping in over and underground stations), as well as regional and high-speed lines, with stations being usable by both types of trains simultaneously, all types of passenger railway stations were considered eligible for review. It has to be noted that classification methodologies originating from railway companies aiming to be used in internal operations were excluded from this analysis, even if they had previously been published in academic literature (e.g. Antonowicz & Moś, 2018). The rationale for this decision was, on the one hand, that these methods and the goals with which such a classification approach is carried out clearly differ in nature from those of their academic counterparts and, on the other hand, that their number and extent make them a separate subject for future research. Organisations such as the International Union of Railways (UIC) have worked on this topic by comparing the classification methodologies used by the member railway operators (International Union of Railways (UIC), 2025).

We searched the scientific databases Scopus and Web of Science for scholarly publications using the following prompt in the article title, abstract, and keywords, with the latest search taking place in August 2025:

(train OR rail*) AND station* AND (classif* OR categori*) AND (austr* OR belgium* OR bulg* OR croat* OR cyp* OR czech* OR danish* OR eston* OR finn* OR french* OR german* OR gree* OR hungar* OR icel* OR irish* OR ital* OR latv* OR lithuan* OR luxemb* OR malt* OR netherland* OR norw* OR pol* OR portug* OR roman* OR slovak* OR sloven* OR span* OR swed* OR switz* OR "United Kingdom" OR brit* OR euro* OR "European Union" OR eu)*

The search provided us with 1,675 sources after deleting duplicates (c.f. Figure 2), which were screened by two independent researchers. To retrieve the relevant publications that were not available via open access, we used the licencing options available

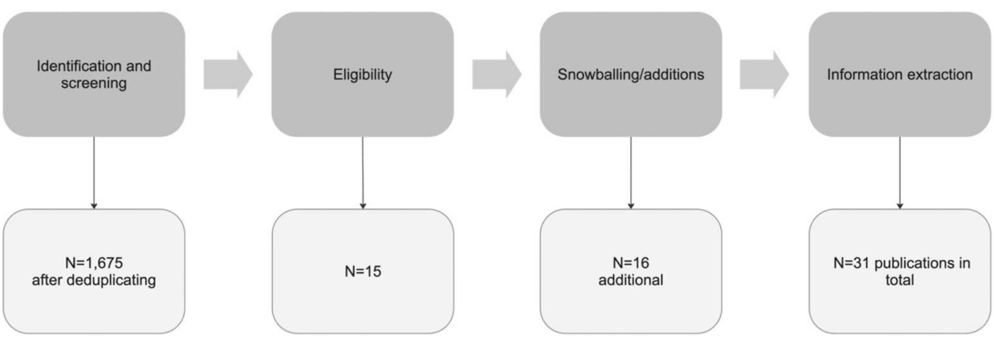

Figure 2. Literature review methodology.

Table 1. Definition of terms: criteria, classes and emergent themes.

Term	Definition
Criterion	A measurable attribute used to evaluate a specific aspect of a railway station or its context, which serves as the basis for grouping stations into classes
Class	The groups into which stations are assigned based on their performance across the criteria
Emergent criteria theme	Higher-level conceptual category that groups individual criteria used in the different studies analysed that share a common subject matter or analytical focus. These themes were not pre-determined but were identified inductively by examining the content and purpose of each criterion across the reviewed classification studies. For example, criteria such as "number of senior citizens in the catchment area" and "number of visitors in the catchment area" were grouped under the theme "demographics".
Emergent class theme	Higher-level category that groups individual station classes used in the different studies analysed that address the same overarching concept. Similar to the emergent themes for criteria, these were identified inductively by analysing the focus and intent of each class set across the reviewed classification studies. For instance, the classes "potential TOD" and "future TOD" were combined into the shared theme "types of TODs."

to the local University Library. Publications that were not accessible this way were retrieved through interlibrary loans from different universities in Germany or by directly contacting the authors. Any publications that were not accessible in one of the aforementioned ways (N = 4) were excluded from further analysis. In total, 15 publications met the eligibility criteria and were further analysed. The references and citations of these papers were searched following a forward snowball effect, producing another 13 publications eligible for analysis. After adding 3 further relevant publications suggested by colleagues, we reached a total of 31 eligible publications. At this stage, the two independent reviewers had an adequate agreement percentage, calculated through percent agreement (McHugh, 2012).

Analysing the characteristics of the classification approaches in our sample, based on the fact that the "essence of a (…) classification is the grouping of station areas that have a common set of morphological and functional characteristics" (Lyu et al., 2016), we examined the different *classification criteria* (chapter 3.2) used in each study, as well as the *classes of stations* (chapter 3.3) defined in each classification study by grouping stations that present similar values (c.f. Table 1). All other characteristics that proved to be decisive for the choice of criteria and classes, for example, the study objectives of each classification study, or spatial influences like the catchment area, were summarised under the umbrella term of *general characteristics* (chapter 3.1).

To structure the diverse criteria and classes identified in the reviewed classification studies, and to capture recent trends and common features in the assessment of railway stations, we defined *emergent themes* for both criteria and classes. Criteria with thematic similarity (e.g. "number of senior citizens in the catchment area" and "number of visitors in the catchment area") were grouped under a shared theme (e.g. "demographics"). Similarly, classes focusing on the same topic (e.g. "potential TOD" and "future TOD") were combined into a shared class theme (e.g. "types of TODs"). This grouping was performed independently and inductively by two researchers, after which results were compared, discussed, and consolidated. Figure 3 illustrates the relationships between classification approaches in the studies analysed, criteria, station classes, and the emergent themes of both criteria and classes.

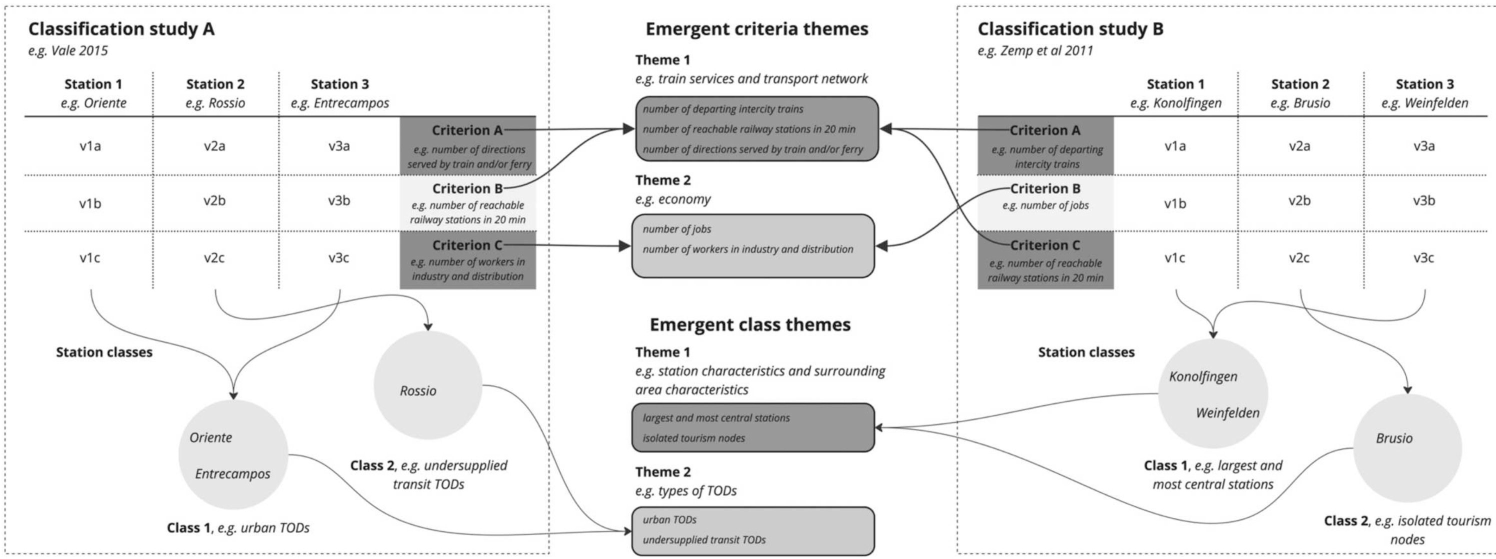

Figure 3. Classification approach analysis methodology. This figure exemplifies the assignment of stations to classes according to their criteria values for each of the studies analysed. The authors of the present paper then assigned both criteria and classes of all of the studies analysed to emergent criteria and class themes according to their thematic focus (cf. Tables 3, 4, and Table A1). Note: v = value. This figure contains only a selection of criteria, classes, and emergent themes from the presented classification approaches.

3. Results

Most of the station classification studies analysed were published after 2008, and from 2011 and onwards, at least one paper about station classification was published almost every year. The papers in our sample mostly follow a similar structure, with three main components:

i. The studies generally start with some *general characteristics* – for example, the goal of the study, the classification approach used, and the spatial context and catchment area as the frame of reference.
ii. Next, a suite of parameters; the *criteria* are being explained.
iii. The studies analysed then generally end with the production of categories of stations, the *classes*.

Thus, the results chapter of this study concentrates on these three primary elements in the subchapters' *general characteristics* (chapter 3.1), *criteria* (chapter 3.2) and *classes* (3.3). It has to be noted that a small number of the studies analysed also use a different structural approach, e.g. Havlena et al. (2014) and Monzón et al. (2016). These studies are nevertheless included in the following analysis.

3.1. General characteristics

Looking at the general characteristics of the studies we analysed, we found that they generally start with the study goals, followed by an explanation of the spatial context, both looking at the region analysed as well as the catchment area, oftentimes specifically diving further into an explanation of the transport modes found on site, which are typically used as rationale to define the catchment area. Then, usually, the classification approach chosen is presented in the studies analysed. Table 2 gives an overview of the different goals, spatial contexts, and approaches to classification that we found.

3.1.1. Study goals

In the reviewed papers, various goals for classifying railway stations can be identified (c.f. Table 2). Most studies aim to establish a foundation for TOD and to identify opportunities to enhance coordination between land use and transport development (e.g. Bertolini, 1999; Caset et al., 2018; Eichhorn et al., 2021). Here, classification systems primarily serve as strategic tools for decision-makers, aiding in scenario construction and supporting strategic spatial and transport development that encourages densification around stations, ultimately increasing public transport use. Certain classifications emphasise land use patterns, comparing stations based on the density and diversity of their land use structures (Soczówka & Żochowska, 2022) or comparatively studying land use changes in the immediate vicinity of railway stations (Wenner & Thierstein, 2021).

Conversely, some authors declare the mere development of a classification method and/or the enhancement of existing methods as their goal (e.g. Reusser et al., 2008; Zemp et al., 2011a), thus indirectly also adopting the goals of the methods they choose to enhance. For example, Vale (2015) aims to complement the NP model with an evaluation of the pedestrian network of each site as a proxy for the walkability friendliness of the station catchment area, while Zheng and Austwick (2023) seek to enhance the NP

Table 2. Catchment area, goals, transport mode and spatial/national context of the classification studies (author's names of NP-based approaches in *italics*).

Classification approach	Selected catchment area radius	Mode of transport at classified stations	Context of classified stations	No. of stations classified	Goal of classification study
Bertolini, 1999	700m	Railway	Amsterdam and Utrecht agglomerations (Netherlands)	31	(Re)development of station areas, allow TOD, identify opportunities for intensification and/or differentiation of urban activities around public transportation nodes.
Ross, 2000	–	Railway	–	–	–
Menéndez et al., 2002	–	Railway	5 European countries	12	Understand which factors lead to successful economic development and urban dynamism using rail accessibility.
Reusser et al., 2008	700m	Railway	Switzerland	1684	Assess all Swiss railway stations in terms of NP functions, enhance the NP model by considering additional indicators relevant to sustainability.
Zemp et al. 2011a	700m	Railway	Switzerland	1700	Contribute to developing station classifications, focusing on the diverse functions, actors, and interests involved.
Ivan et al., 2012	700m	Railway	Ostrava (Czech Republic)	11	Assess redevelopment potential of specific railway stations and evaluate the suitability of the NP model in a commuter-focused city.
Papa et al., 2013	500m	Metro and train modes	Naples (Italy)	212	Support decision-making based on NTOD (network TOD) and polycentric principles by identifying the most suitable station areas for new activities
Havlena et al., 2014	Nearby city	Railway	–	–	Provide conclusions on station facilities, such as ticket offices, services, and waiting areas, to help infrastructure managers and operators optimise service levels
Marti-Henneberg, 2015	25km	High-speed rail	Parts of Europe and Asia	174	Identify low-attraction HSR stations, analyse their geographic concentration, and develop a method to assess user attraction capacity to improve public investment allocation.
Vale, 2015	700m	Train and ferry boat	Lisbon metropolitan area (Portugal)	49	Enhance the NP model for TOD planning by adding pedestrian network evaluation as a walkability proxy and introducing a new clustering based on node, place, and pedestrian indexes.
Monzón et al., 2016	Nearby city	Railway	–	–	Decrease the barriers to the use of public transport, improve quality, and propose a business model related to the interchange typology.
Stoilova & Nikolova, 2016	Nearby city	Fast and express trains	Bulgaria	98	Provide a basis for developing transport services for various passenger train types by creating and comparing technological schemes for rail lines or networks.

(*Continued*)

Table 2. Continued.

Classification approach	Selected catchment area radius	Mode of transport at classified stations	Context of classified stations	No. of stations classified	Goal of classification study
Singh et al., 2017	800m	Railway	City region of Arnhem and Nijmegen (Netherlands)	21	Identify areas with strong TOD but poor transit access, and areas near quality transit where transit orientation needs improvement.
Groenendijk et al., 2018	300 m core influence area, 800 m influence area for metro stations, and 1200 m influence area for train stations	Different transit hubs, including metro and train modes	Rotterdam, (Netherlands)	32	Extension of the NP model to include experience value.
Caset et al., 2018	1200, 700, 800 m, 3000m	Regional express rail	Brussels Capital Region (Belgium)	144	Provide empirical evidence on land use – transport integration of RER (regional express railway) stations to support strategic policy, by mapping accessibility, testing station typologies through cluster analysis, and evaluating the impact of different catchment area sizes on results.
Vale et al., 2018	500m	Metro	Lisbon (Portugal)	49	Assess the extended NP model's applicability at the urban scale and whether TOD types from the metropolitan level persist locally, using Lisbon's subway station typology to guide planning, zoning, fiscal policy, and integration of transport, land use, and urban design.
Caset et al., 2019	1200m	Railway	Flanders and Brussels-Capital Region (Belgium)	287	Identify strategic transport nodes best suited for urban development and develop a broader set of empirical parameters for regional railway station typologies.
Pucci, 2019	400 m, 1500m	Suburban railway	Lombardy Region (Italy)	104	Scenario building to improve services and connectivity at suburban stations by expanding catchment areas, densifying around key stations, or shifting development from poorly served areas.
Nigro et al., 2019	1 km, 2,6 km, 4,4 km, 6km	Railway	Campania (Italy)	6	Extend the NP analysis to explore land use and public transport relationships in non-metropolitan contexts.
Zhang et al., 2019	960m	Metro	London (UK)	270	Extend the NPD approach by incorporating a strategic network dimension.
Wenner et al., 2020	700m	Suburban and regional trains	Munich Metropolitan Region (Germany)	512	Compare accessibility and functional density at Munich's stations and propose a planning strategy based on integrated urban and transport development.
Borghetti, Colombo, et al., 2021	850m	Railway	Lombardy Region (Italy)	11	Apply the 15-minute city concept to railway stations, treating them as starting points for last-mile travel, and develop a decision-support tool.

(*Continued*)

Table 2. Continued.

Classification approach	Selected catchment area radius	Mode of transport at classified stations	Context of classified stations	No. of stations classified	Goal of classification study
Borghetti, Longo, et al., 2021	Isochrones: 5, 10, 15 min walking time	Railway	Lombardy Region (Italy)	4	Apply the 15-minute city concept to railway stations, treating them as starting points for last-mile travel.
Eichhorn et al., 2021	15 min walking isochrones	Regional and/or suburban trains	North Rhine-Westphalia (Germany)	747	Provide recommendations for urban planners and policymakers to enhance integrated land use and transport development.
Wenner & Thierstein, 2021	1500m	High-speed rail	11 countries in Europe	232	Conduct comparative international studies on land use changes around HSR (high-speed rail) stations to complement case studies and capture local dynamics beyond quantitative methods.
Zhang et al., 2021	–	Underground network, light rail, overground	London (UK)	642	Enable planners to better understand each station's network role and tailor redevelopment strategies accordingly.
Soczówka & Żochowska, 2022	800m	Railway	Metropolitan association of Upper Silesia and Dąbrowa Basin (Poland)	65	Compare stations by land use density and diversity, and identify those with low levels of both.
Kruszyna & Makuch, 2023	–	Railway	Wrocław agglomeration (Poland)	21	Measure level of service (LOS) to inform management, planning, and design in both railway infrastructure and spatial development.
Panzaru & Aun, 2023	–	railway	European countries	50	Assist travellers in choosing the optimal station for their journey while ensuring the best possible experience.
Pazzini et al., 2023	–	Railway	Emilia Romagna (Italy)	33	Identify the required quality and interventions to improve bicycle accessibility in mobility hubs and enhance bike-train intermodality.
Zheng & Austwick, 2023	700m	Metrolink system and commuter train system	Manchester (UK)	177	Enhance the NPD model by adding system centrality and green space indicators to better account for green space.

model with centrality and green space indicators. A further goal present in the studies that are based on the NP model is the verification of whether this model is usable in specific contexts and circumstances, such as in the case of non-metropolitan contexts (Nigro et al., 2019) or in cities with a prevailing commuting function (Ivan et al., 2012).

Some authors use the instrument of classification to specify requirements for station equipment (e.g. ticket offices) and support infrastructure managers to optimise the scale of services (Havlena et al., 2014) or to develop transport services for various passenger train types (Stoilova & Nikolova, 2016), thus concentrating less on the spatial planning approach. Last but not least, a significant group of examined classifications has rather specific goals, such as Pazzini et al. (2023), who aim to define the interventions necessary in order to increase intermodality between bicycles and trains, or Borghetti, Colombo, et al. (2021) and Borghetti, Longo, et al. (2021), who apply the concept of the 15 min city to railway stations.

3.1.2. Spatial context (region, catchment area)

Within the European scope analysed, the stations were located in the Netherlands (N = 3), Switzerland (N = 2), the Czech Republic (N = 1), Italy (N = 6), Portugal (N = 2), Bulgaria (N = 1), Belgium (N = 2), Germany (N = 2), the United Kingdom (N = 2) and Poland (N = 2). Though most studies examine one country or region, some authors choose to compare different stations and/or areas in the European context (e.g. Menéndez et al., 2002; Panzaru & Aun, 2023; Wenner & Thierstein, 2021). A special case is the study by Marti-Henneberg (2015), where case studies from all over Europe are compared to comparable Asian counterparts. The case studies not only vary in their geographical location, but also in their scale, meaning the number of stations which are used to build classes (c.f. Table 2).

Almost all classification studies analysed define a walkable radius as the catchment area for their classification. Many authors choose to adopt the 700 m radius, which has been defined as walkable in Bertolini (1999), yet other approaches can also be found, such as 960 m, which is defined as a walkable radius for metro services by Zhang et al. (2019). Yet, what is coined as walkable seems to also be influenced by the mode of transport offered at the station. We notice that authors consider smaller catchment areas when classifying urban short-distance modes of transit compared to larger areas for long-distance modes of transit. For example, Groenendijk et al. (2018), within the same study, choose an 800 m area for metro stations, compared to 1,200 m for railway stations. Similarly, Vale et al. (2018) chooses a 500 m area for metro stations, compared to Vale (2015) using 700 m for railway stations. Similarly, the catchment area increases in high-speed rail classifications, e.g. with Wenner and Thierstein (2021), who choose a 1500 m radius, arguing that "high-speed rail, as the top tier of rail transport, justifies longer access distances" (p. 10).

However, not all classification studies analysed rely on a catchment area solely defined by walkability. Some authors choose to use different catchment areas corresponding to different modes of access to the station. For example, Nigro et al. (2019) compare different catchment areas for walking (1 km), biking (2.6 km), public transport (4.4 km) and car access (6 km), all corresponding to 12 min. Similarly, Pucci (2019) compares a walkable radius of 400 m and an accessibility radius with motorised vehicles and/or bicycle (1500 m), and Caset et al. (2018) also compare different distances corresponding to different timeframes for walking and cycling. Such approaches are usually used within a suburban (e.g. Pucci, 2019) or rural (e.g. Nigro et al., 2019) setting, highlighting the fact that transport and land use planning have to consider different modes of first- and last-mile journeys in suburban and rural areas than in metropolitan/urban areas.

Catchment areas are shaped not only by walkability or available transport modes but also by the conceptual focus of a study. For instance, Borghetti, Colombo, et al. (2021) and Borghetti, Longo, et al. (2021) apply the 15-minute city concept to railway stations, adopting an 850 m radius to represent a 15-minute walk. In contrast, Havlena et al. (2014) focus on station facilities and define the nearby city as the catchment area without specifying an exact radius, since the immediate station environment is not central to their classification approach. Similarly, studies such as Ross (2000) and Panzaru and Aun (2023) completely omit the use of a catchment area, since due to the goals of their classification studies, all criteria are concentrated on the station itself.

3.1.3. Referenced classification approaches

We find that almost half of the studies analysed refer to the NP model, using it as the basic approach for their classification study. Other approaches used as a basis are the NPD variation (Vale, 2015), and the operationalised TOD index approach (Evans & Pratt, 2007), as illustrated in Figure 4.

The classification approaches examined in this review are generally of a quantitative nature. Exceptions to this rule are Menéndez et al. (2002), Ross (2000) and Wenner and Thierstein (2021), who use qualitative methods. Furthermore, some authors integrate qualitative elements (e.g. interviews) within their framework of quantitative methods in order to augment the criteria set (e.g. Groenendijk et al., 2018; Reusser et al., 2008). The exact way in which the results of quantitative/qualitative classification methodologies are designed differs throughout the studies and is not part of this research. Rather, we aim to provide an overview of the different approaches used. For a more in-depth insight into exact calculations, the reader is referred to the studies cited throughout this paper.

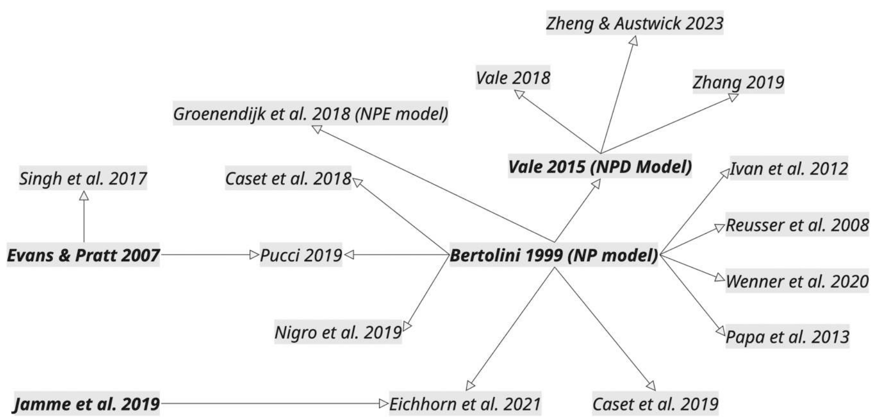

Figure 4. Most important references for classification approaches (in bold letters) and reviewed papers that are based on these approaches.

3.2. Criteria for classification

The second topic of analysis consists of the criteria that are used to classify stations and station areas. Following the nature of the general classification approaches used (c.f. chapter 3.1), these criteria are mostly quantitative. Table A1 (in Appendix) provides a detailed overview of the different classification criteria and of the authors who use them. In order to accommodate all criteria mentioned in the examined studies in one table, some similar criteria have been consolidated into one (e.g. "train frequency" and "number of stopping trains in peak hour" into "daily frequency of train services / number of stopping trains").

It becomes evident that several rationales underpin the authors' selection of criteria. For those studies that draw upon an established classification approach (c.f. Figure 4), the reference to that approach is indispensable in determining the criteria. This is particularly true for studies based on the NP model (Bertolini, 1999), the NPD variation (Vale, 2015), and the operationalised TOD index approach (Evans & Pratt, 2007). However, even when studies are based on a specific existing approach, authors still make modifications to the criteria set. These modifications are influenced by the availability of data, contextual factors, and the specific objectives of the classification study (c.f. Figure 5), with the latter being the main driving force in determining the criteria chosen:

Table 2 shows that when referencing an existing model, typically, the original objectives are used, complemented by specific aspects. For instance, Vale (2015) adapts the primary goals of the NP model (e.g. redevelopment of station areas, identification of opportunities for intensification and/or differentiation of urban activities around public transportation nodes) by optimising the TOD aspect, introducing a pedestrian network evaluation as a walkability proxy. This results in a novel classification approach based on node, place, and pedestrian indexes (also known as the NPD model). Zheng and Austwick (2023) further explore the NPD approach by incorporating, among others, green space indicators. Their classification approach incorporates the fundamental criteria of the NP and NPD models, along with additional criteria such as criteria on the green space ratio per capita. A slightly differing example is Eichhorn et al. (2021), who use the NP model as a central conceptual and methodological foundation in their study, yet choose to operationalise it with criteria based on the six TOD dimensions (6-D) (Jamme et al., 2019) acquired through literature review. Interestingly and in contrast to studies such as the one by Vale (2015), Eichhorn et al. (2021) argue that the design dimension is difficult to capture through comprehensive quantitative analysis, thus excluding it from their classification approach.

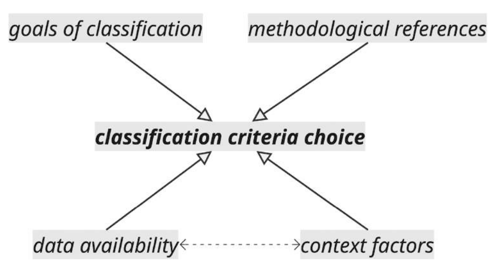

Figure 5. Factors that influence classification criteria choice.

Pucci (2019) also bases her classification on two reference approaches, namely the TOD index (Evans & Pratt, 2007) and the NP model (Bertolini, 1999); however, by not integrating them, but by classifying the same stations using both methods, and by comparing the results. In the case of the NP-based classification approach, Pucci selects a set of criteria based on a literature review of various NP model variations, while in the case of the TOD index, a comparative analysis is being carried out on the main operative experiences of the TOD index, "to find the most suitable indicators for measuring TOD levels" (Pucci, 2019, p. 72).

Classification studies not based on the NP model typically have more specific criteria because they are tailored to specific classification aims rather than relying on a common referenced approach. Consequently, their comparability is limited. For example, Wenner and Thierstein (2021) aim to capture local dynamics by complementing case studies with international comparisons of land use changes around HSR (high-speed rail) stations. Thus, their criteria set differs significantly from NP studies and includes criteria such as the number of HSR stations in the area and their location with regard to the city they serve. Similarly, Pazzini et al. (2023) adopt a narrowly focused set of criteria assessing intermodal mobility, reflecting their objective to identify necessary interventions for improving bicycle accessibility in mobility hubs and fostering bike–train intermodality.

Following Vale (2015), it is noticeable that the criteria selections based on the NP model never follow the original criteria set 1:1, which Vale (2015) traces back to the fact that "all additional applications of the model had methodological alterations, justified by the absence of available data, by local specificities and/or by intentions to improve the methodology itself" (p. 73). In fact, one noticeable reason for the adjustment of the criteria suggested is, in fact, data availability, with Pucci (2019), who bases her study on the NP model, clearly mentioning a lack of available data for some criteria. In a similar vein, Reusser et al. (2008) omit the criterion of "car parking capacity" (included in the NP approach) due to the lack of available data and choose to add only additional criteria suggested in expert interviews with concurrent data availability.

Another aspect influencing the choice of criteria is the local context. For example, Ivan et al. (2012) tailor their criteria set (which is based on the NP model) to the needs of their case study by removing indicators about bicycle access to the station, since in the case study area the "use of bike and ride system remains very rare and unusual" (Ivan et al., 2012, p. 146). At the same time, they incorporate a new indicator, namely the "accessibility of railway stations by suburban buses [… since] this transport mode is often used by people who travel to or from locations close to Ostrava but without any possibility of traveling there by train" (Ivan et al., 2012, p. 147). Similarly, Vale (2015) excludes accessibility by bicycle since bike commuting has less than a 1% modal share in their Lisbon case study, rather extending the concept of stations to include "not only train stations but also ferryboat stations, due to the importance of ferryboat traveling in Lisbon" (Vale, 2015; p. 73). Nigro et al. (2019), based on the NP model, are addressing the peripheral contextual influence on the classification approach by, among others, adding car-based transport-area place criteria due to the peripheral location of the classified stations, arguing that "there is a strong rationale for using this 'park and ride', or possibly 'kiss and ride' option, especially in stations at the interface of low-density suburban areas and high-density urban areas" (Nigro et al., 2019, p. 112), showing a link between the selection of criteria and spatial characteristics of the catchment area.

Table 3: Overview of emergent themes for criteria of the classification studies analyzed. For a full overview of criteria within emergent themes, refer to Table A1 in the Appendix

Emergent themes of criteria	*Bertolini 1999*	Ross 2000	Menendez et al. 2002	*Reusser et al. 2008*	Zemp et al. 2011a	*Ivan et al. 2012*	*Papa et al. 2013*	Havlena et al. 2015	Marti-Henneberg 2015	*Vale 2015*	Stoilova & Nikolova 2016	Monzon et al. 2016	Singh et al. 2017	*Groenedijk et al. 2018*	*Caset et al. 2018*	*Vale et al. 2018*	*Pucci 2019*	*Nigro et al. 2019*	*Zhang et al. 2019*	*Caset et al. 2019*	*Wenner et al. 2020*	Zhang et al. 2021	Wenner & Thierstein 2021	Borghetti et al. 2021a	Borghetti et al. 2021b	*Eichhorn et al. 2021*	Soczowka & Zochowska 2022	Kruszyna & Makuch 2023	Pazzini et al. 2023	Panzaru & Aun 2023	*Zheng & Austwick 2023*
STATION AS A TRANSPORT HUB																															
Theme 1: Train services and transport network *(e.g. passenger frequency, Singh et al. 2017, or network position, Caset et al., 2018)*	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x			x				x	x
Theme 2: Station characteristics *(e.g. facilities, staffing, Reusser et al., 2008, or architectural quality, Groenendijk et al., 2018)*		x		x							x	x	x	x				x					x					x		x	
Theme 3: Intermodality *(e.g. frequency of other transport modes, Zemp et al., 2011a, or accessibility, Nigro et al., 2019)*	x			x	x	x		x		x	x	x	x	x	x	x	x	x	x	x			x	x		x		x	x	x	x
STATION CONTEXT																															
Theme 1: Demographics *(e.g. population density, specific groups; Ivan et al., 2012)*	x			x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x			x					x
Theme 2: Economy *(e.g. jobs or firms by sector; Wenner et al., 2020)*	x			x	x	x	x	x	x	x	x		x	x	x	x	x	x	x		x										x
Theme 3: Functional mix *(e.g. activities, land-use diversity, Singh et al., 2017; service–train ratios; Pucci, 2019)*	x			x				x		x	x	x	x	x	x	x	x		x	x	x			x	x	x	x	x			x

(*Continued*)

Table 3: Continued.

Emergent themes of criteria	*Bertolini 1999*	Ross 2000	Menendez et al. 2002	*Reusser et al. 2008*	Zemp et al. 2011a	*Ivan et al. 2012*	*Papa et al. 2013*	Havlena et al. 2015	Marti-Henneberg 2015	*Vale 2015*	Stoilova & Nikolova 2016	Monzon et al. 2016	Singh et al. 2017	*Groenedijk et al. 2018*	*Caset et al. 2018*	*Vale et al. 2018*	*Pucci 2019*	*Nigro et al. 2019*	*Zhang et al. 2019*	*Caset et al. 2019*	*Wenner et al. 2020*	Zhang et al. 2021	Wenner & Thierstein 2021	Borghetti et al. 2021a	Borghetti et al. 2021b	*Eichhorn et al. 2021*	Soczowka & Zochowska 2022	Kruszyna & Makuch 2023	Pazzini et al. 2023	Panzaru & Aun 2023	*Zheng & Austwick 2023*
Theme 4: Relation to centrality and centrality characteristics *(e.g. distance to town centre, Reusser et al., 2008; building density, Pucci, 2019)*			x	x	x	x			x		x	x					x						x					x			
Theme 5: Spatial planning *(e.g. densification potential; Wenner et al., 2020)*						x				x		x	x	x	x	x	x	x	x	x	x					x		x			x
Theme 6: Other *(e.g. population–job balance, accessibility change; Wenner et al., 2020)*																					x	x									

To structure the diverse criteria found in the reviewed classification approaches, we defined emergent themes of criteria – groups that capture topics and trends in station classification criteria. We found six emergent themes that can be organised into two main categories: *station as a transport hub* and *station context* (paralleling the "node" and "place" dimensions of the NP model), with the first containing three themes and the second encompassing six themes; see Table 3 (for a more in-depth look, see also Table A1 in the Appendix).

Reflecting on the trends of criteria choices over time, one can notice a turn towards spatial and design factors in more recent studies, possibly due to the influence of Vale's (2015) NPD model variation. This is in line with the growing importance of the TOD concept in recent literature and planning practice in the European context (Jamme et al., 2019; Thomas et al., 2018), and underlines Vale's (2015) argument that "by combining the NP model with an evaluation of the walkability of each station area, a deeper TOD evaluation can be performed" (Vale, 2015, p. 72), building on the fact that "TOD projects (…) are seen as dependent on good urban design to coordinate transportation modes, mix land uses and create an appealing public space within a limited area" (Thomas et al., 2018, p. 1208). As can be seen in Table 3, the emerging theme of spatial planning is gaining importance in classification approaches developed roughly since 2015. Criteria such as intersection density, pedshed, length of footpath network, and other similar characteristics of roads within the catchment area are present in many recent studies and are reflected in their goals as well, which concentrate on the interplay of urban space and transport, such as land use-transport integration (e.g. Caset et al., 2018), urban development (Caset et al., 2019) or TOD types (Vale et al., 2018).

Beyond identifying common criteria themes, the comparison indicates that criteria selections systematically reflect the stated goals of each study and the case study context. For example, TOD-oriented classifications with goals that reflect accessibility, urban design and land use-transport integration extend the original NP dimensions with walkability and spatial design indicators (e.g. Vale, 2015; Caset et al., 2018), whereas studies with operational or service planning aims prioritise facilities, service frequency, and modal supply (e.g. Stoilova & Nikolova, 2016; Kruszyna & Makuch, 2023). Classification approaches following very specific hypotheses, such as the possibility of a station being the core of 15-minute city districts (e.g. Borghetti, Colombo, et al., 2021) tend to use very limited and specific criteria sets, aligned with the nature of their research question. This suggests that the criteria used in a study are not only a function of available data or context but are strategically chosen to evaluate specific planning questions.

Reflecting on contextual factors, a comparison of Table 2 and Table A1 indicates that studies adopting a broader spatial scope (e.g. country or state) generally avoid highly specific criteria such as site-specific modes (e.g. ferry boat, Vale, 2015; suburban bus, Ivan et al., 2012) or detailed spatial context variables (e.g. green space ratio per capita, Zheng & Austwick, 2023; streetscape characteristics in Singh et al., 2017), which are more common in city- or city-region-scale analyses. This may reflect limited applicability of such criteria across large territories or the lack of consistent data (e.g. Reusser et al., 2008). Apart from the scale, the location of the case study of each classification approach influences the criteria choice. For example, research focusing on rural or peripheral settings tends to incorporate car-based accessibility and long-distance access measures (e.g. Nigro et al., 2019), while metropolitan studies place greater emphasis on multimodality and pedestrian access (e.g. Groenendijk et al., 2018).

However, despite substantial variation in criteria across classification approaches, there is a recurring use of basic indicators such as the number of residents in the area/population density – possibly as a result of the influence of common referenced approaches in many studies – (c.f. Figure 4), thus providing a degree of comparability of most classification approaches.

3.3. Classes

The station classes – derived by grouping stations with similar values across the classification criteria – vary considerably across the analysed studies. One of the most striking findings of this review is that none of the examined classification studies employ directly comparable classes, which limits the potential for a detailed cross-study comparison. Nevertheless, it is possible to identify eight recurring generic emergent themes of classes, as summarized in Table 4.

Examining existing classification approaches like the NP model, which acts as a basis for many studies (c.f. Figure 4), we observe that contrary to the criteria selection, where authors who base their classification on an existing approach usually adopt (and then adapt) its basic criteria set, the classes for studies based on the NP model (author names in *italic* letters in Table 4) do not necessarily adopt (and adapt) the model's proposed class typology (classes such as unsustained node and unsustained place). For example, Groenendijk et al. (2018) extend the NP model, adding an experience factor, yet, though many of the criteria used are derived from Bertolini (1999), the classes defined are of a completely different nature (e.g. metropolitan centre, modern city, gate quarter). A similar approach can be observed in Reusser et al. (2008), whose methodology is based on the NP model; yet, the resulting classes (named cluster 1-5) are of a different nature than the ones in the NP model. However, there are classification studies that use the classes of the referenced model either partly or fully. In the former case, Vale (2015) adopts specific terms of Bertolini's (1999) classes by integrating a TOD dimension (e.g. unbalanced TODs, balanced TADs), while in the latter case, Pucci (2019) fully adopts not only the NP methodology, but also the classes of the NP model.

Over time, a shift from more station-oriented classes (e.g. rail-to-rail interchanges in Ross, 2000, emergent class theme 1), classes where the station and the catchment area/nearest city are handled as two separate entities (e.g. edge station in Menéndez et al., 2002, emergent class theme 2) or classes that focus on the station, having yet to take into account its surroundings (e.g. isolated tourism nodes in Zemp et al., 2011a, emergent class theme 3), to more space-oriented class typologies, where the station is being observed as an integral part of a station area. This leads to classes that either represent station areas (e.g. regional centre in Groenendijk et al., 2018, emergent class theme 6), or bundle and classify stations and station areas as TODs/TADs (e.g. urban TODs in Vale, 2015, emergent class theme 5), thus adopting a fully integrative approach, where the station and its surrounding area are summarized as a "TOD". This may be the result of the growing importance of the TOD concept in European planning practice (Jamme et

Table 4: Emergent themes of classes (author's names of NP-based approaches in *italics*)

Emergent themes of classes	*Bertolini, 1999*	Ross, 2000	Menendez et al. 2002	*Reusser et al., 2008*	Zemp et al. 2011a	*Ivan et al., 2012*	*Papa et al., 2013*	Havlena et al., 2014	Marti-Henneberg, 2015	*Vale, 2015*	Stoilova & Nikolova, 2016	Monzón et al., 2016	Singh et al., 2017	*Groenendijk et al., 2018*	*Caset et al., 2018*	*Vale et al., 2018*	*Pucci, 2019*	*Nigro et al., 2019*	*Zhang et al., 2019*	*Caset et al., 2019*	*Wenner et al., 2020*	Zhang et al., 2021	Wenner & Thierstein, 2021	Borghetti, Colombo, et al., 2021	Borghetti, Longo, et al., 2021	*Eichhorn et al., 2021*	Soczówka & Żochowska, 2022	Kruszyna & Makuch, 2023	Pazzini et al., 2023	Panzaru & Aun, 2023	*Zheng & Austwick, 2023*
Theme 1: Station (only) characteristics e.g. Rail-to-rail interchanges (Ross 2000); Non-hub connector nodes (Zhang et al. 2021)		x										x										x									
Theme 2: Relation city/station e.g. edge station (Menéndez et al. 2002)			x									x											x								
Theme 3: Station characteristics and surrounding area characteristics e.g. may correspond to large railway nodes in cities with population over 100 000, with higher quality trains stopping (Havlena et al. 2015)				x	x			x			x									x											
Theme 4: (Partly) align with the NP Model class typology e.g. High unbalanced place (Papa et al.2013)	x						x			x					x	x	x				x										
Theme 5: Types of TODs *e.g. Urban TODs (Vale 2015)*										x						x	x									x					x
Theme 6: Station Area types e.g. Regional centre (Groenendijk et al. 2018)														x					x		x		x				x				
Theme 7: User centered classes e.g. small origin stations with very small catchment areas (Caset et al. 2019)																				x											
Theme 8: No classes						x			x				x					x						x	x			x	x	x	

al., 2019; Thomas et al., 2018) and is reflected in the criteria of the studies that adopt TOD-oriented classes.

The emergence of increasingly space-oriented class themes is partly related to a shift in aims of the studies. Research that employs class types incorporating catchment area characteristics (e.g. emergent themes 3, 4, 5, and 6) often focuses on the coordinated development of transport and land use, particularly in transit-oriented catchment area planning. However, despite this general tendency, no consistent patterns emerge when examining the relationship between classification scopes and class themes in detail. For instance, although Papa et al. (2013) and Vale et al. (2018) share similar classification goals, they adopt different class themes. Similarly, some authors who expand the NP model and identify its further development as part of their objective – thus at least partly adopting the NP model's aims – may still base their classifications partly on the original NP class structure (e.g. Vale, 2015), while others propose entirely new classes (e.g. Reusser et al., 2008).

The situation is clearer for classification studies that do not produce classes (Table 4, theme 8). In such cases, the primary objective often shifts from categorising stations into groups to evaluating them individually based on specific performance criteria. This methodological choice is closely tied to the intended scope of the study. For example, Kruszyna and Makuch (2023) focus on measuring the level of service at railway stations to inform infrastructure management and design. Similarly, Ivan et al. (2012) aim to assess the redevelopment potential of individual stations, rather than attempting to group them into broader categories.

While transport mode types did influence the definition of catchment areas, we found no clear link between transport mode types and classes: For example, Vale (2015) and Vale et al. (2018) use very similar classes, though the first study classifies railway (and ferry boat) stations, whereas the second concentrates on metro stations. On a broader scope, it was interesting to see what kind of spatial context influenced the definition of classes: For example, Reusser et al. (2008) consider the touristic potential of a station catchment area and include touristic activities in some class descriptions, such as "(…) close to important leisure activities such as skiing or hiking (both for residents and tourists)" (p. 199), relating it to the touristic potential of the Swiss alpine region. Similarly, Zemp et al. (2011a) also include classes such as *tiny touristy stations and isolated tourism nodes*, coming from the same context. These examples illustrate how specific local or national characteristics can influence the granularity of classification schemes.

As can be expected, the choice of the criteria set is a very decisive factor for the produced classes, and it reflects the objectives of a classification study. Especially when the criteria concentrate on a specific topic, this is usually reflected in the classes. For example, Caset et al. (2019) include criteria that, among others, concentrate on user behaviour, such as the percentage of people using the station as a destination for secondary education purposes, and the resulting classes reflect a user-centred approach. Similarly, studies producing classes that emphasise the importance of the catchment area of the station (e.g. emergent class themes 5 and 6) are based on a classification process involving space-oriented criteria. For example, Pucci (2019) is assessing the potential transformability of an area, using indicators such as transformation areas in urban planning and vacant areas, whereas Eichhorn et al. (2021) adopt space-oriented criteria such as standard land values and developable land potential.

4. Concluding discussion

The aim of this study was to systematically review the different studies and approaches to railway station classification in Europe, thus creating a solid basis for future uniform approaches aiming at the classification and development of European railway stations. By contributing to the understanding of the different characteristics, development conditions and potentials of a railway station, it is also paving the way for the sustainable transformation of railway stations and their surrounding areas. In the following, we discuss the results and their limitations in light of other scientific findings, give an outlook for future research and discuss the study's policy implications.

4.1. Key findings

Examining 31 academic publications, we uncovered a diverse landscape of classification approaches that vary in general characteristics such as objectives, catchment area analysed or study approach, as well as in the criteria and classes identified. The following key findings emerged:

1. Most classification studies have a three-part structure: They begin with (i) some general characteristics, describing the study goal, the spatial context and the classification approach, before then (ii) developing classification criteria and (iii) applying them in a case study area, leading to the building of classes. The two parts are methodologically interconnected (c.f. key findings 3, 4, 6).
2. A large number of classification studies (15/31) are based on the NP model (Bertolini, 1999). The NPD variation by Vale (2015) is crucial for the spatial turn in classification criteria. The TOD Index by Evans and Pratt (2007), developed in the U.S., is also referenced as an important theoretical framework.
3. A diverse landscape of criteria is being used in the examined classification approaches, which can be structured into *emergent criteria themes* (Table 3; Table A1). Many classification studies share similar sets of criteria. The choice of criteria is based on the approach on which the study is based (such as the NP model), the objectives, the context of the development, as well as the data availability in the application case study.
4. Contrary to the criteria, which are sometimes shared across different classification studies and approaches, there are no uniform or shared classes across the reviewed studies; only generic class themes (Table 4) can be defined. The choice of classes in each classification study is partly based on the classification approach chosen (such as the NP model), on the objective of the study, as well as on the criteria and the context where the study is developed and applied.
5. In recent years, we have observed a shift from more station-oriented classes and criteria to more space-oriented class typologies and criteria themes, where the station is observed as an integral part of a station (catchment) area, highlighting the growing importance of the TOD concept in European planning practice (Jamme et al., 2019; Thomas et al., 2018).
6. Different catchment areas are defined in the examined classification studies. The choice of catchment area is based on the mode(s) of transport at the station, the objectives of the classification study, and the spatial context of the classification case study.

7. The objectives of each study (c.f. Table 2) play a crucial role in determining the choice of classes and criteria. In recent years, more authors have focused on supporting the development of the catchment area as a TOD, based on coordinated transport, land-use, and urban design parameters (e.g. Vale, 2015). They select corresponding categories and criteria sets that reflect this goal. Conversely, some classification studies adopt very specific objectives, such as exploring bike-train intermodality (Pazzini et al., 2023), and use specific criteria sets accordingly.

4.2. Policy implications and recommendations; recommendations for future research

To enhance the competitiveness of rail transport in the EU, the development of stations and their surrounding areas is essential, yet, stations are often neglected in the planning process, falling "in the gap between transport and urban agendas" (Lunardon et al., 2023, p. 1) along with diverging responsibilities, making them overlooked by urban planners and policymakers. The classification of stations can be a valuable tool to develop railway stations and their surrounding areas at a European level (Nared et al., 2020), enabling an assessment of the redevelopment potential of railway stations (Ivan et al., 2012) and supporting policy decision-making based on polycentric principles (Papa et al., 2013). Our literature review uncovers several policy implications that necessitate attention to facilitate a more uniform, larger-scale approach to station classification and development within the European context. Consequently, we derived policy recommendations and future research directions:

1. *Data availability* plays a crucial role in shaping the selection of criteria for classification and ultimately determines the classes and outcomes of classification studies. This leads to relevant criteria sometimes being overlooked due to data limitations. To address this, we propose ensuring the collection of this data by including corresponding notes on data collection in European policies. Given the spatial nature of (parts of this) data, it is imperative to establish a common radius of catchment area beforehand.
2. The complex landscape of station classes does not facilitate a meaningful comparison of different stations and contexts, thus limiting the potential of station classification being used as a strategic tool for spatial and transport development on a European level. *Guidelines for class definition or certain types of classes* that are flexible enough to include context-specific needs yet comparable enough for common strategic planning could assist in station area development policies at a European level and are highlighted as a topic for future research.
3. Due to the many heterogeneous criteria used in classification studies, the *use of emergent themes* defined in this paper can assist in the strategic orientation of a novel classification approach. Especially the criteria in the emergent theme "station context" are of high value for exploring the potential of station classification to assist TOD planning (Vale, 2015). Furthermore, emergent themes can assist the development of common criteria sets or shared conceptual dimensions for a European-wide classification approach.
4. The growing *importance of spatial criteria* in classification studies (Nigro et al., 2019) raises the question of how urban design around stations can be measured. This

question has also been raised by authors such as Vale (2015), acknowledging that walkability not only entails aspects like connectivity and straightness, but also the attractiveness of the routes, aesthetics, the safety and security of places, and other physical aspects such as slope and the existence of barriers. The measurement of these characteristics through purely quantitative methods can be challenging, hence Caset et al. (2019) suggest the critical validation of classification studies through qualitative methods in urban design studio environments and further research.

5. While *sustainable transformation pathways of railway station areas* are present in recent literature (Lunardon et al., 2023; Spinosa, 2023), there is very limited attention to sustainability criteria in classification studies (e.g. inclusion of green infrastructure criteria in Zheng & Austwick, 2023). Here, we recommend further research and suggest the use of station classification as a basis for the conceptualisation of new normative frameworks – e.g. in the form of a model – for the exploration of stations' potential sustainable transformation pathways.
6. Current classification approaches are often designed for specific case studies, which means they may not be suitable for other contexts, such as rural areas where the needs for station classification vary (Nigro et al., 2019). We recommend that further discussions be held regarding the *applicability of existing classification methods* across different national and spatial contexts. This would serve as an important first step toward developing a uniform classification approach for larger European regions.

While European transport policies and recent research projects emphasise station area development on a European scale (European Commission, 2021, 2023; Nared et al., 2020), the instrument of classification that can assist in the development and concretisation of such policies (Caset et al., 2018; Pucci, 2019) appears to be predominantly applied at the regional or national level, without challenging national borders or analysing larger-scale European areas. To facilitate the implementation of larger-scale policies, we thus propose utilising station classification as a tool to support the collective development of European transport nodes, analysing their hierarchies, differences and development potentials in a transport network of nodes and places (Bertolini, 1999). In Europe, such systems of nodes and places should not only be outlined by national or regional borders, but rather should "be defined in functional terms as 'functional urban areas', probably as a combined result of the catchment area and mobility (commuting) behaviour" (European University Institute, 2024, p. 3), potentially even combining different transport modes such as railway and ferry (Vale, 2015). Hence, "the removal of technical and operational barriers at European cross-border sections would contribute to the attractiveness and competitiveness of rail transport" (European Union Agency for Railways, 2022). Building on a uniform set of station classification criteria like the one suggested in this review, future research should explore the development of new approaches which correspond to large-scale functional areas or whole geographic transport corridors (such as the ones defined in the TEN-T framework, e.g. Rhine-Danube corridor).

The results of this paper clearly show that there are challenges to be addressed before such frameworks can be realistically applied, or even developed, such as the (un)availability of standardized data, the conceptual differences in class definition and catchment areas, and the different themes of classes, or lack thereof. The results show that tackling these challenges with simple measures, such as the definition of standardized datasets and the conceptual alignment of the class and criteria themes, can be promising initial steps towards comparability of local classification approaches and a first step towards European-scale classifications.

4.3. Limitations

While our research aims to review existing station classification studies and approaches and provide relevant policy recommendations for future station area development, several limitations should be considered when interpreting the findings. First, the geographical scope was limited to classification systems developed or applied within the European context. While we argue that the specific historical, policy and density-related conditions in Europe call for a detailed analysis within this context, we nevertheless acknowledge that approaches from non-European settings might nevertheless be very valuable for cross-case learning. Second, classification methodologies developed by railway companies for internal operational use were excluded. As such, certain practice-oriented insights and data-driven methods may not be represented. Third, the search was conducted exclusively in English (using English keywords), which may have resulted in the omission of relevant non-English publications. Finally, the review did not engage with the mathematical or algorithmic details of clustering techniques used in the classification processes. Instead, the focus was on the more general process of classification, the criteria applied and their categorisation in emergent themes, as well as the resulting station classes. Furthermore, it focused on the rationale behind the selection of these parameters, examining factors such as theoretical references, classification objectives, and contextual influences.

4.4. Concluding remarks

This study delves into the complex landscape of railway station classification studies, including their structure, similarities and differences. It emphasises the value of station classification as a tool for sustainable transport and land-use development and offers recommendations for maximising its potential in future transport studies at the European level – for example, through the development of uniform classification methods for all railway stations within a large geographical region. It also aims to support the applicability of academic classification in real-world planning practice, which has so far been limited, with the notable exception of the NP Model used by Dutch public authorities and railway companies (Peek et al., 2006). Furthermore, this study is highly relevant for facilitating the exchange between academics and railway industry practitioners. Although the classification systems employed by railway companies often differ significantly from those examined in this paper, it is worth noting that many such companies are currently revising their approaches – frequently incorporating indicators similar to those found in academic literature (International Union of Railways (UIC), 2025). This trend further underscores the significance of this review as a tool for summarising and communicating academic approaches, serving as a reference for industry classifications. Lastly, since station area development pathways are often conceptualised through models that provide a shared framework for understanding (Zemp et al., 2011b), we strongly recommend using station classification as a valuable analytical tool for planning and fostering collaboration among the various stakeholders involved in transit-oriented development (TOD) – including railway companies, public administrations, and private entities. Such collaboration is essential for developing common and sustainable transformation pathways for railway stations and their surrounding areas (Lunardon et al., 2023).

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Appendix

Table A1. Criteria of the classification approaches classified in emergent themes (author's names of NP-based approaches in *italics*).

Emergent themes of the criteria	*Bertolini*, 1999	Ross, 2000	Menendez et al., 2002	*Reusser et al.*, 2008	Zemp et al. 2011	*Ivan et al.*, 2012	*Papa et al.*, 2013	Havlena et al., 2014	Marti-Henneberg, 2015	*Vale*, 2015	Stoilova & Nikolova 2016	Monzon et al. 2016	Singh et al., 2017	*Groenendijk et al.*, 2018	*Caset et al.*, 2018
STATION AS A TRANSPORT HUB															
Theme 1: Train services and transport network	**x**			**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Number of directions served by train	x			x				x	x	x			x	x	x
Type of train services				x	x			x						x	
Daily frequency of train services / number of stopping trains	x			x		x		x		x			x	x	x
Number of stations within 20/45 min of train travel	x			x	x					x					x
Passenger frequency (including comparison, e.g. between weekdays and weekends)				x							x	x	x		
Travelled passenger – kilometres											x				
% Of people using the station as origin/destination station															
% Of people using the station as the origin station who live within a specific distance															
% Of people using the station as a destination station for specific education/work/other purposes															
Closeness/betweenness/degree centrality/shortest distance between nodes							x								x
International travel possibilities															
Gravitational accessibility															
Utilization of transit services															
More than one railway company															
Delays/waiting times															
Number of HSR stations in the area															
Theme 2: Station characteristics		**x**		**x**							**x**	**x**	**x**	**x**	
Services/ facilities/staffing at the station				x								x	x	x	

(*Continued*)

Table A1. Continued.

Emergent themes of the criteria	*Bertolini, 1999*	Ross, 2000	Menendez et al., 2002	*Reusser et al., 2008*	Zemp et al. 2011	*Ivan et al., 2012*	*Papa et al., 2013*	Havlena et al., 2014	Marti-Henneberg, 2015	*Vale, 2015*	Stoilova & Nikolova 2016	Monzon et al. 2016	Singh et al., 2017	*Groenendijk et al., 2018*	*Caset et al., 2018*
Station layout		x													
Functional types		x													
Number of foster starting tracks cash											x				
Station construction cost															
Architectural quality/renovation														x	
Safety at the station													x		
Theme 3: Intermodality	**x**			**x**	**x**	**x**		**x**		**x**	**x**	**x**	**x**	**x**	**x**
Number of directions/routes by bus, tram, underground/other transit modes (not necessarily all three) / existence of these transport modes	x			x						x		x	x	x	x
Daily frequency by bus, tram, underground (not necessarily all three)	x			x	x	x				x				x	x
Accessibility of bus/tram/metro stop/car parking															
Distance from the closest motorway access	x			x						x				x	x
Car parking (capacity/utilization); P + R	x									x			x	x	x
Bicycle (paths) infrastructure	x			x									x		x
Bicycle parking capacity/utilization	x												x	x	x
Generic importance of the station as a public transport change node/station accessibility								x			x				
Presence of car/bike/ride-sharing service, and EV charging points														x	x
Distance travelled by passengers from the station											x				
Dependency on cars to reach the station															
STATION CONTEXT															
Theme 1: Demographics	**x**			**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**		**x**	**x**	**x**
Number of residents in the area/population density	x			x	x	x	x	x	x	x	x		x	x	x
Employment levels/rate of unemployed with basic education						x							x		
Number of students											x				
Number of senior citizens											x				
Average distance to jobs and residents/number of population reachable in a given time					x										
Ratio of inhabitants to employees														x	

(*Continued*)

Table A1. Continued.

Emergent themes of the criteria	*Bertolini, 1999*	Ross, 2000	Menendez et al., 2002	*Reusser et al., 2008*	Zemp et al. 2011	*Ivan et al., 2012*	*Papa et al., 2013*	Havlena et al., 2014	Marti-Henneberg, 2015	*Vale, 2015*	Stoilova & Nikolova 2016	Monzon et al. 2016	Singh et al., 2017	*Groenendijk et al., 2018*	*Caset et al., 2018*
Number of visitors														x	
Theme 2: Economy	**x**			**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**		**x**	**x**	**x**
Number of workers (or jobs) per each of four economic clusters (not necessarily in all four)/job density	x			x	x	x	x			x	x		x	x	x
Income factors (purchase power parity (PPP) / average wage)									x		x				
Number/density of firms/business establishments													x		
Station surroundings as a tourist or recreational target / arriving tourists per 1000 residents					x			x							
Tax earnings of municipalities													x		
Theme 3: Functional mix	**x**			**x**				**x**		**x**	**x**	**x**	**x**	**x**	**x**
Degree of functional/land use mix or diversity/shannon/ contagion index/mixedness of land uses	x			x						x			x		x
Surface/presence/distance/density of pois/amenities/ industrial activities/commercial and tertiary activities/ services or educational/buildings				x				x		x	x	x	x	x	x
Proportion of services to trains															
Number of flats/residential buildings						x									
Theme 4: Relation to centrality and centrality characteristics			**x**	**x**	**x**	**x**			**x**		**x**	**x**			
Distance to town centre/location in comparison to city/cities			x	x					x			x			
Core urban area (built-up area)/building density						x									
Area of nearby town											x				
Characteristics of nearby centrality (e.g. main station of regional centre district/administrative centre)					x						x				
Theme 5: Spatial planning						**x**				**x**		**x**	**x**	**x**	**x**
Length, traffic, intersection density/ratio of the number of street segments and street intersections/other characteristics of roads within the catchment area													x		x

(*Continued*)

Table A1. Continued.

Emergent themes of the criteria	*Bertolini, 1999*	Ross, 2000	Menendez et al., 2002	*Reusser et al., 2008*	Zemp et al. 2011	*Ivan et al., 2012*	*Papa et al., 2013*	Havlena et al., 2014	Marti-Henneberg, 2015	*Vale, 2015*	Stoilova & Nikolova 2016	Monzon et al. 2016	Singh et al., 2017	*Groenendijk et al., 2018*	*Caset et al., 2018*
Accessible/ traversable network length/ pedshed /length of footpath network/ sidewalks										x			x	x	x
Integrated development plan												x			
Land prices/ development costs						x									
Densification/ new building potential/ transformability															
Presence of protected areas															
Green space ratio per capita															
Length of street segments flanked by buildings (public-private realm interface)															
Theme 6: Other															
The surplus or deficit of local place value compared to accessibility															
The surplus or deficit of local population size compared to jobs and facilities															
Accessibility change															
Within-module degree z-score and intermodule participant coefficient *p* (z-*p* score)															

Table A1. Continued.

Emergent themes of the criteria	*Vale et al., 2018*	*Pucci, 2019*	*Nigro et al., 2019*	*Zhang et al., 2019*	*Caset et al., 2019*	*Wenner et al., 2020*	Zhang et al., 2021
STATION AS A TRANSPORT HUB							
Theme 1: Train services and transport network	**x**	**x**	**x**	**x**	**x**	**x**	
Number of directions served by train	x	x	x	x			
Type of train services		x					
Daily frequency of train services / number of stopping trains	x	x	x	x	x		
Number of stations within 20/45 min of train travel	x			x			
Passenger frequency (including comparison, e.g. between weekdays and weekends)				x	x		
Travelled passenger – kilometres							
% Of people using the station as origin/destination station					x		
% Of people using the station as the origin station who live within a specific distance					x		
% Of people using the station as a destination station for specific education/work/other purposes					x		
Closeness/betweenness/degree centrality/shortest distance between nodes				x	x		
International travel possibilities							
Gravitational accessibility						x	
Utilization of transit services		x					
More than one railway company							
Delays/waiting times							
Number of HSR stations in the area							
Theme 2: Station characteristics			**x**				
Services/ facilities/staffing at the station			x				
Station layout							
Functional types							
Number of foster starting tracks cash							
Station construction cost							
Architectural quality/renovation							
Safety at the station							
Theme 3: Intermodality	**x**	**x**	**x**	**x**	**x**		
Number of directions/routes by bus, tram, underground/other transit modes (not necessarily all three) / existence of these transport modes	x	x	x	x	x		
Daily frequency by bus, tram, underground (not necessarily all three)	x		x	x	x		
Accessibility of bus/tram/metro stop/car parking			x				

(*Continued*)

Table A1. Continued.

Emergent themes of the criteria	*Vale et al.,* 2018	*Pucci,* 2019	*Nigro et al.,* 2019	*Zhang et al.,* 2019	*Caset et al.,* 2019	*Wenner et al.,* 2020	Zhang et al., 2021
Distance from the closest motorway access	x			x			
Car parking (capacity/utilization); P + R	x	x	x	x	x		
Bicycle (paths) infrastructure			x		x		
Bicycle parking capacity/utilization		x			x		
Generic importance of the station as a public transport change node/station accessibility							
Presence of car/bike/ride-sharing service, and EV charging points							
Distance travelled by passengers from the station		x					
Dependency on cars to reach the station		x					
STATION CONTEXT							
Theme 1: Demographics	**x**	**x**	**x**	**x**	**x**	**x**	
Number of residents in the area/population density	x	x	x	x	x	x	
Employment levels/rate of unemployed with basic education							
Number of students		x	x				
Number of senior citizens							
Average distance to jobs and residents/number of population reachable in a given time							
Ratio of inhabitants to employees							
Number of visitors							
Theme 2: Economy	**x**	**x**	**x**	**x**		**x**	
Number of workers (or jobs) per each of four economic clusters (not necessarily in all four)/job density	x	x	x	x			
Income factors (purchase power parity (PPP) / average wage)							
Number/density of firms/business establishments						x	
Station surroundings as a tourist or recreational target / arriving tourists per 1000 residents							
Tax earnings of municipalities							
Theme 3: Functional mix	**x**	**x**		**x**	**x**	**x**	
Degree of functional/land use mix or diversity/shannon/contagion index/mixedness of land uses	x			x	x		
Surface/presence/distance/density of pois/amenities/ industrial activities/commercial and tertiary activities/services or educational/ buildings		x		x		x	
Proportion of services to trains		x					
Number of flats/residential buildings							
Theme 4: Relation to centrality and centrality characteristics		**x**					
Distance to town centre/location in comparison to city/cities							
Core urban area (built-up area)/building density		x					

(*Continued*)

Table A1. Continued.

Emergent themes of the criteria	*Vale et al., 2018*	*Pucci, 2019*	*Nigro et al., 2019*	*Zhang et al., 2019*	*Caset et al., 2019*	*Wenner et al., 2020*	Zhang et al., 2021
Area of nearby town							
Characteristics of nearby centrality (e.g. main station of regional centre district/administrative centre)							
Theme 5: Spatial planning	**x**	**x**	**x**	**x**	**x**	**x**	
Length, traffic, intersection density/ratio of the number of street segments and street intersections/other characteristics of roads within the catchment area	x		x	x	x		
Accessible/ traversable network length/ pedshed /length of footpath network/ sidewalks	x		x	x			
Integrated development plan							
Land prices/ development costs							
Densification/ new building potential/ transformability		x				x	
Presence of protected areas		x					
Green space ratio per capita							
Length of street segments flanked by buildings (public-private realm interface)					x		
Theme 6: Other						**x**	**x**
The surplus or deficit of local place value compared to accessibility						x	
The surplus or deficit of local population size compared to jobs and facilities						x	
Accessibility change						x	
Within-module degree z-score and intermodule participant coefficient *p* (z-*p* score)							x

Table A1. Continued.

Emergent themes of the criteria	Wenner & Thierstein, 2021	Borghetti, Colombo, et al., 2021	Borghetti, Longo, et al., 2021	*Eichhorn et al., 2021*	Soczowka & Zochowska 2022	Kruszyna & Makuch, 2023	Pazzini et al., 2023	Panzaru & Aun, 2023	*Zheng & Austwick, 2023*
STATION AS A TRANSPORT HUB									
Theme 1: Train services and transport network	**x**			**x**				**x**	**x**
Number of directions served by train									x
Type of train services	x								
Daily frequency of train services / number of stopping trains				x					x
Number of stations within 20/45 min of train travel									x
Passenger frequency (including comparison, e.g. between weekdays and weekends)									x
Travelled passenger – kilometres									
% Of people using the station as origin/destination station									
% Of people using the station as the origin station who live within a specific distance									
% Of people using the station as a destination station for specific education/work/other purposes									
Closeness/betweenness/degree centrality/shortest distance between nodes									x
International travel possibilities								x	
Gravitational accessibility									
Utilization of transit services									
More than one railway company								x	
Delays/waiting times								x	
Number of HSR stations in the area	x								
Theme 2: Station characteristics	**x**					**x**		**x**	
Services/ facilities/staffing at the station						x		x	
Station layout									
Functional types									
Number of foster starting tracks cash									
Station construction cost	x								
Architectural quality/renovation									
Safety at the station									
Theme 3: Intermodality	**x**	**x**		**x**		**x**	**x**	**x**	**x**
				x		x			x

(*Continued*)

Table A1. Continued.

Emergent themes of the criteria	Wenner & Thierstein, 2021	Borghetti, Colombo, et al., 2021	Borghetti, Longo, et al., 2021	*Eichhorn et al., 2021*	Soczowka & Zochowska 2022	Kruszyna & Makuch, 2023	Pazzini et al., 2023	Panzaru & Aun, 2023	*Zheng & Austwick, 2023*
Number of directions/routes by bus, tram, underground/other transit modes (not necessarily all three) / existence of these transport modes									
Daily frequency by bus, tram, underground (not necessarily all three)				x					
Accessibility of bus/tram/metro stop/car parking		x				x			
Distance from the closest motorway access									x
Car parking (capacity/utilization); P + R				x		x			x
Bicycle (paths) infrastructure							x		
Bicycle parking capacity/utilization									x
Generic importance of the station as a public transport change node/station accessibility	x					x			
Presence of car/bike/ride-sharing service, and EV charging points		x						x	
Distance travelled by passengers from the station									
Dependency on cars to reach the station									
STATION CONTEXT									
Theme 1: Demographics	**x**			**x**					**x**
Number of residents in the area/population density	x			x					x
Employment levels/rate of unemployed with basic education									
Number of students									
Number of senior citizens									
Average distance to jobs and residents/number of population reachable in a given time				x					
Ratio of inhabitants to employees									
Number of visitors									
Theme 2: Economy									**x**
Number of workers (or jobs) per each of four economic clusters (not necessarily in all four)/job density									x
Income factors (purchase power parity (PPP) / average wage)									
Number/density of firms/business establishments									
Station surroundings as a tourist or recreational target / arriving tourists per 1000 residents									
Tax earnings of municipalities									
Theme 3: Functional mix		**x**	**x**	**x**	**x**	**x**			**x**
Degree of functional/land use mix or diversity/shannon/contagion index/mixedness of land uses				x					x

(*Continued*)

Table A1. Continued.

Emergent themes of the criteria	Wenner & Thierstein, 2021	Borghetti, Colombo, et al., 2021	Borghetti, Longo, et al., 2021	*Eichhorn et al., 2021*	Soczowka & Zochowska 2022	Kruszyna & Makuch, 2023	Pazzini et al., 2023	Panzaru & Aun, 2023	*Zheng & Austwick, 2023*
Surface/presence/distance/density of pois/amenities/ industrial activities/commercial and tertiary activities/services or educational/buildings		x	x		x	x			x
Proportion of services to trains									
Number of flats/residential buildings					x				
Theme 4: Relation to centrality and centrality characteristics	**x**					**x**			
Distance to town centre/location in comparison to city/cities	x					x			
Core urban area (built-up area)/building density									
Area of nearby town									
Characteristics of nearby centrality (e.g. main station of regional centre district/administrative centre)									
Theme 5: Spatial planning				**x**		**x**			**x**
Length, traffic, intersection density/ratio of the number of street segments and street intersections/other characteristics of roads within the catchment area						x			x
Accessible/ traversable network length/ pedshed /length of footpath network/ sidewalks				x					x
Integrated development plan									
Land prices/ development costs				x					
Densification/ new building potential/ transformability				x					
Presence of protected areas									
Green space ratio per capita									x
Length of street segments flanked by buildings (public-private realm interface)									
Theme 6: Other									
The surplus or deficit of local place value compared to accessibility									
The surplus or deficit of local population size compared to jobs and facilities									
Accessibility change									
Within-module degree z-score and intermodule participant coefficient *p* (z-*p* score)									