9th Year Folder 09 N° 01 pp 148-169
ISSN 2543-375X EISSN 2676-1645

Transit-Oriented Development: A Review of Planning/Assessing Methodology, Scale, Location, Criteria and Indicators.

التنمية الموجهة بالنقل:
مراجعة منهجية التخطيط/القياس، المستوى، المكان، المعايير والمؤشرات.

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Received: 16/06/2023 Accepted: 08/01/2024

Abstract:

Planning and assessing methods of transit-oriented development are computationally demanding and time-consuming. Particularly when selecting between criteria with indicators is critical. This study aims to solve this question and detect the gaps in transit-oriented development planning/assessing Methodology by conducting a systematic review that seeks to understand the criteria for its planning and the methods used for its measurement in six topics: methodology, principles, scale, location, criteria and indicators. For this purpose, we employed the Publish or Perish software to collect a bibliographic database from Scopus documentation to identify the literature stating transit-oriented development worldwide from its emergence in 1993 until 2021.

After a meticulous reading of 726 papers already found, only 34 articles were pertinent. The data systematization of the articles was then performed in the QDA Miner-Lite to convert textual data into quantitative relative data by dividing each literature into six issues: Methodology, principles, scale, location, criteria and indicators. The

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findings revealed evidence for a significant presence of research over corridors and regional contexts, besides the inexistence of studies directed to African and Latin American urban centres. While existing studies provide a groundwork for assessing TOD potential, there remain significant gaps in the criteria employed. Notably, economic feasibility, human-centric considerations, environmental impacts, and the local neighbourhood dimension are often overlooked in the current TOD literature. Analyses by continent unveiled a variety of planning/assessing methodologies in East Asia and Europe. While, Southeast Asia, North America and Asia/Australia rely on assessment studies. This study provides researchers/planers with an inventory of TOD planning/assessing tools, a perception of prospects for future research, and the flaws that must be addressed. Therefore, future research shall expand urban morphology and transit aspects to include economic concentration, social aspects and environmental impacts. Moreover, maintaining an equal number of indicators for each criterion can provide consistency, while alternative approaches like differential weighting may be necessary if certain criteria possess greater influence or require more nuanced calculation. Besides that, every criterion must have representative indicators tailored to the unique circumstances of each city.

Keywords: Transit-oriented development; planning/assessing methodology; criteria; indicators.

الملخص:

تتطلب عملية تخطيط وتقييم مقاربة التنمية الموجهة بالنقل حسابات معقدة وطويلة. لا سيما عملية اختيار المعايير والمؤشرات الدّالة عليها. تهدف هذه الدراسة إلى إيجاد حلول لهذا الاشكال بتسهيل هذه العملية من خلال الكشف عن ثغرات منهجية تخطيطها وتقييمها وحصر معايير التخطيط وطرق قياسها حول العالم. لهذا الغرض، استخدمنا برنامج Publish or Perish لجمع البيانات الببليوغرافية من قاعدة سكوبس وتحديد المقالات المرتبطة بالمقاربة، منذ ظهورها عام 1993 حتى عام 2021. بعد قراءة دقيقة لـ 726 ورقة بحثية، تم حصر 34 مقالًا ذا صلة، ثم عولجت المقالات في QDA Miner-Lite لتحويل المعطيات الكتابية إلى معطيات نسبية كمية وصنفت في ستة محاور مرتبطة بتقييم المقاربة وتخطيطها من حيث: المنهجية، المبادئ، المقياس، المكان، المعايير والمؤشرات. أظهرت النتائج اهتماما بالممرات والمجالات الإقليمية مع إهمال المستوى المحلي، بالإضافة إلى غياب دراسات عن المقاربة في مدن إفريقيا وأمريكا اللاتينية. كما تم الكشف عن اختلال في التعبير عن المعايير

والمؤشرات وتنوعها، حيث همشت المعايير الاقتصادية والاجتماعية والآثار البيئية في الأدبيات السابقة. كشفت التحليلات حسب القارة عن تنوع منهجيات التخطيط والتقييم في شرق آسيا وأوروبا. في المقابل، لا نجد سوى دراسات التقييم في المناطق الأخرى. توفر هذه الدراسة قائمة بالأدوات الأنسب لتقييم وتخطيط المقاربة مستقبلا. لذلك، يجب أن توسع الأبحاث المستقبلية اهتمامها نحو التركز الاقتصادي، والجوانب الاجتماعية، والتأثيرات البيئية للمقاربة. علاوة على ذلك، يجب أن يكون عدد المؤشرات متساويًا لكل معيار، أو على الأقل أن تكون موزعة بشكل أفضل. بالإضافة إلى ذلك، يجب أن يكون لكل معيار مؤشراته الأكثر دلالة وفقاً لخصائص واحتياجات كل مدينة.

الكلمات المفتاحية: التنمية الموجهة بالنقل، منهجية التخطيط/القياس، المعايير، المؤشرات.

1. Introduction

Transit Oriented Development (TOD) has received much attention over the last two decades (Jamme et al., 2019), as a sustainable urban planning approach (Pan et al., 2017) that aims to conjugate aspects of the built environment around a transit station, which would be performed in a compact, mixed, connected, and active mode-guided space (Calthorpe, 1993; Singh et al., 2014).

Many studies are dedicated to expanding experiences and quantitative evaluation methods of TOD all over the world (Kamruzzaman et al., 2014), while others emphasise more theoretical discussions about general challenges concerning the concept (Abdi & Lamíquiz-Daudén, 2022). Nonetheless, the planning and assessment of TOD approaches involve significant computational resources and time commitment (L. Liu et al., 2020; Motieyan & Mesgari, 2018). This burden is particularly increased when confronted with the selection of criteria and their associated indicators.

Therefore, this study aims to detect the gaps in TOD planning/assessment Methodology by questioning its planning criteria and measuring methods since the emergence of the TOD approach in the early 1990s (Calthorpe, 1993). Moreover, since TOD approach provides sustainable cities in different regions all over the world (Knowles et al., 2020), this research offers practical support for TOD approach by identifying the most relevant TOD criteria and indicators from past and ongoing studies of TOD planning and assessment,

which can make the complex mechanisms supporting sustainable urban development in diverse regions more perceptible.

From earlier studies, this review advances in three axes. Firstly, we explore the structure and composition of all TOD's planning criteria and indicators, examining their internal coherence and relevance, while other studies exhibit a focus on specific aspects (Renne & Newman, 2002; Yang & Pojani, 2017). Secondly, the extensive timeframe of TOD research examined over three decades, while other works execute temporally focused reviews (He et al., 2018; Langlois et al., 2015). Finally, we extend the evaluation to comprehend the geographical literature distribution, going beyond studies centred in specific places (Jamme et al., 2019; Tan et al., 2014). To accomplish the research aims, the study covers all journals indexed in Scopus that discussed TOD's planning criteria within the mentioned period.

The work structure goes as follows: this introduction section opens the discussion and presents its aims; in methodology, we explicate the adopted approaches and methodologies to construct the review; in results and discussion, the outcomes are widely illustrated and debated; ultimately, in conclusion, we expatiated on considerations and possibilities brought by our research.

2. Methodology

Primarily, it is necessary to establish a path to build a solid and effective literature collection concerning TOD's methods. Thus, this study deployed the Publish or Perish free software to gather bibliographic data from the Scopus database by identifying the literature that states TOD as keywords in the title or within the abstract. Narrowing the search to avoid repeated results that can be published in different works of literature (Jamme et al., 2019), we focused on articles, reviews and reports published in scientific journals, dismissing other bibliographic forms such as thesis, conferences, books. Examining TOD research amassed in the Scopus database since the year of 1993 until June 6th 2021, displayed 726 articles placed in 238 different journals, including 25 reviews and one report.

Subsequently, the Mendeley software was applied to classify the indicated literature to choose the best pertinent works for the subject of this paper. To achieve this, we pursued the occurrence of the terms "planning" and "criteria" in the literature's titles, abstract and content. From all the gathered data, 91 papers mentioned the first term, and three stated the second. To conclude the collection, a meticulous reading was carried out, resulting in 34 papers judged and selected for

this review; (Akbari et al., 2018; Berawi et al., 2019; Caset & Teixeira, 2021; Dorsey & Mulder, 2013; Furlan & Al-Mohannadi, 2020; Hale, 2010; W. Huang & Wey, 2019; X. Huang et al., 2021; L'Hostis et al., 2016; Y. Li et al., 2010; Z. Li et al., 2019; Liang et al., 2020; Lin & Gau, 2006; Lin & Li, 2008; J. H. Liu et al., 2018; L. Liu et al., 2020; Lord et al., 2015; Ma et al., 2018; Motieyan & Mesgari, 2017, 2018; Mueller et al., 2018; Nelson et al., 2015; Olaru et al., 2019; Pan et al., 2017; Shao et al., 2020; Singh et al., 2014; Su, Zhang, He, et al., 2021; Su, Zhang, Wang, et al., 2021; Taki & Maatouk, 2018; Thomas & Bertolini, 2014; Wey, 2015; Wey et al., 2016; Xu & Yan, 2021; Zaina et al., 2016).

With those data, the Lite version of QDA Miner was employed to organize the content systematically. This software facilitates qualitative analysis of textual elements by classifying the verified structure counting on a subdivision called codes, which makes possible a mathematical proportion of the codes' frequencies for the global partition of the categories (Avery, 2021). Through comparative and critical analysis, we divided the reviewed literature into six distinct thematic clusters: Methodology, TOD principles, TOD scale, TOD location, TOD criteria and indicators. In each one, we designed categories and codes to gather the literature content, thus in a two-level hierarchy.

The following subsections set forth the categories and codes for each topic under the classes of general approach and planning criteria and indicators.

2.1. TOD general approach

In the approach review, the articles were put under a lens concerning their proper research methodology, the applied TOD principles, the inspected TOD scale, and the geographical placement of the case studies around the globe. These topics were defined to shape precise and confine studies assessment, which provides a perspective of the employed scientific ways.

For the topic of methodology, the categories used were "Assessment", which indicates research guided by the evaluation of TOD, and the category of "Planning", which gathers studies about TOD strategy. Then, four codes were derived within the first category and two for the other one. In the "Principles" topic, three categories were designed to embrace the three terms that shape the TOD concept: "Transit (Mobility)", aimed at transit and traffic issues; "Oriented (Built Environment)", which embraces urban space configuration; and "Development (Urban Life)", that assembles planning and

sustainability aspects. The 11 codes were defined to capture the essence of the T, O, and D principles, evaluated in each study Figure N° 2.

Concerning the "TOD Scale" topic, we designed two categories associated with the territory examined around TOD stations in the literature. "Focused Territory" aims at specific places and surroundings, being divided into the codes "Around stations", guided to a proper transit stop and "Local", directed to other neighbourhoods apart from transit lines. On the other hand, "Embracing Territory" brings together studies that assess more than a specific location, which can be segregated into the codes "Corridors/lines" and "Urban/regional" Figure N°.

Lastly, the topic "Location" offers a nuanced understanding of the geographic context of all other topics, considering the division into two areas: Developing Countries and Developed Countries

2.2. TOD planning criteria and indicators

For criteria and indicators, we counted the main subject of the studies investigated, i.e., precisely the aspects aimed by the review. In the criteria topic, we proposed novel categories to represent better TOD premises developed from earlier work (Gerald et al., 2021; ITDP 2017) as substitutes for the five dimensions (5Ds) suggested by Ewing and Cervero (2010). This process establishes a framework for classifying criteria that effectively designate pertinent TOD principles. Thus, the five categories elaborated are Compact, Diverse, EcoMobility, Equitable, and Resilient TOD Figure N°, distinguishing them from the 5Ds, which do not provide that, with more explanation in section 3.1.5.

The indicators are the variables used for TOD measuring, assessment and planning (Ibraeva et al., 2020). For their turn, they were crypto-graphed into 75 different codes within 12 categories. These have been reduced to nine categories with 26 representative codes by merging less used indicators (mentioned three times or less, i.e., represent 1.8% of the mentioned indicators) with similar categories. For example, 'living quality' indicators were divided between the 'environment' and 'social' categories, allocated in the 'open spaces' and the 'provision of public services' indicators. However, some indicators were not merged regardless of their score since there is no similar category with which they can be amalgamated. For example, the 'TOD policy' indicator in

Figure N°:.

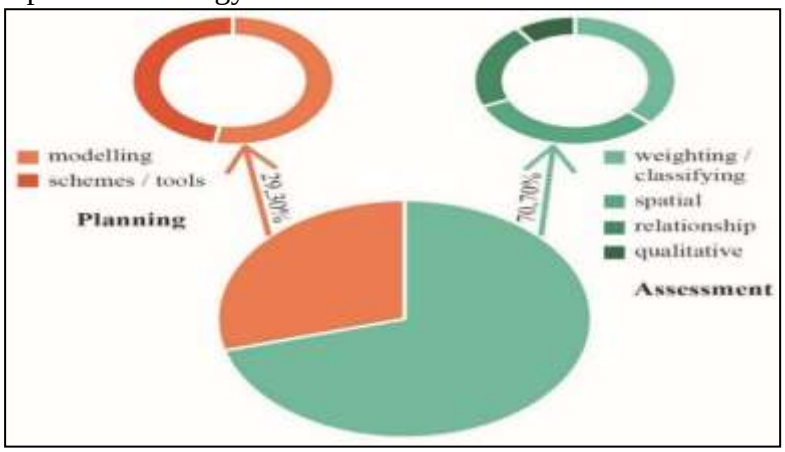
3. Results and discussion

After the designation of codes and categories and their insertion in QDA Miner, with respective data from the literature, as explained above, we discuss the results, which are divided into two subsections. General analyses bring considerations within each topic, with explanatory graphs showing the quantitative outcomes of categories and codes. Then, Analyses by continent presents a transversal examination of the topics concerning geographical contexts revealed by the location.

3.1. General analyses

Prominent aspects brought by our review can be discussed within each topic area. Therefore, the more prevalent aspects and those that are understated serve as a vital framework for structuring the content of the literature.

Figure N° 1: Graph of the coding frequency identified in the topic Methodology



Source: The authors, (2022).

3.1.1. TOD methodology

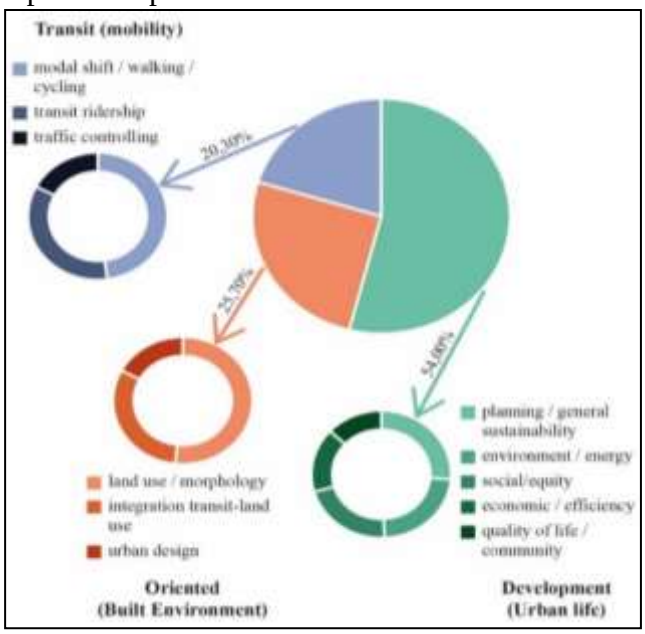
Considering the proportion identified through QDA Miner Figure N° 1, we infer that most papers conduct evaluations of the existing TOD reality, especially in classifications of spatial aspects. Therefore, the relationship between variables, which includes correlation techniques and more qualitative analyses, is reduced in the total share. This occurrence highlights the importance given to quantitative assessments guided to reduce and clarify the complexity of TOD spaces. In addition, the studies dedicated to planning ways of TOD implementation are divided almost equally between more objective modelling tools and those aimed at descriptive schemes.

3.1.2. TOD principles

Concerning TOD Principles

Figure N° 2, results show that more than half of the works verified involve aspects concerning the development portion of TOD, which refers to general urban planning components and sustainability dimensions (economic, social and environmental). Most of the studies allocated in this category are distributed repeatedly in more than one code. In their turn, characteristics of the Oriented scope are discussed in its association with land use, urban design, or the integration of urban space and mobility. Finally, aspects of transit appear with the lowest proportion, which indicates the limitation of investigations examining the potential of improving transit aspects of TOD.

Figure N° 2: Graph of the coding frequency identified in the topic-Principles

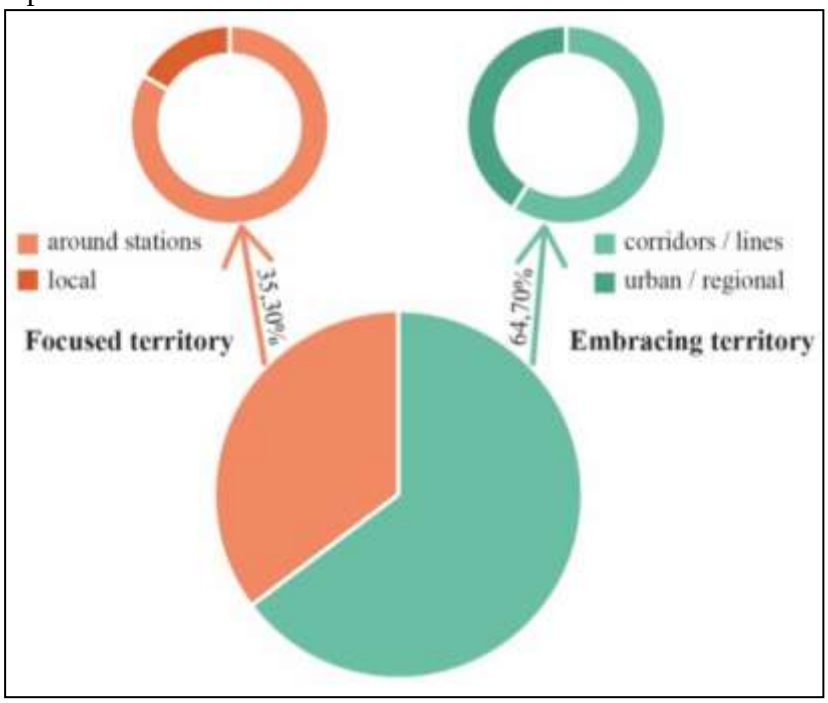


Source: The authors, (2022).

3.1.3. TOD scale

Regarding the space scale evaluated in the studies, the results showed a significant presence of research over corridors and regional contexts Figure N°3. It contrasts with the less appealing works related to specific surroundings, an outcome indicating a tendency to more embracing studies and not linked to isolated contexts.

Figure N°3: Graph of the coding frequency identified in the topic Scale

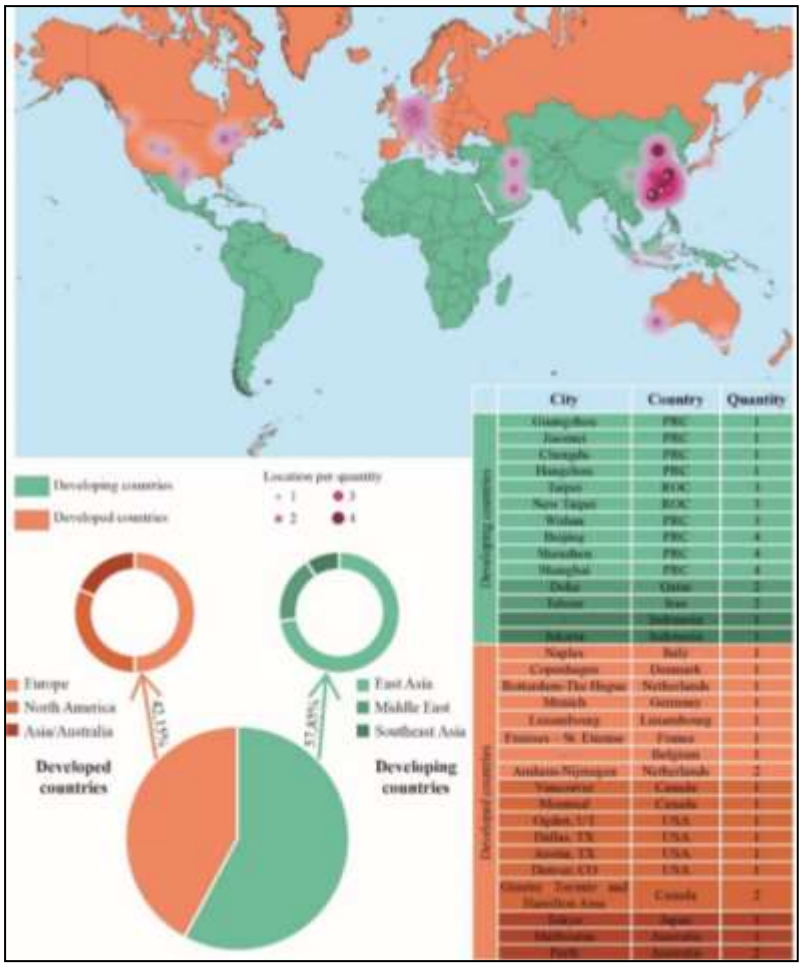


Source: The authors, (2022).

3.1.4. TOD location

The location assessment Figure N° revealed the concentration of studies over developing countries, with all located in Asia or the Middle East. About the research focused on cities within the developed world, European and North American places excel. This division makes explicit for the inexistence of studies directed to African and Latin American urban centres.

Figure N°4: Graph and geographic distribution of the coding frequency identified in the topic Location.



Source: The authors, (2022).

Note: Two studies do not focus on a specific city/metropolis but consider aspects of entire regions or countries. It is the case of one Indonesian case and the Belgian case.

3.1.5. TOD planning/assessing criteria and indicators

Regarding these two topics here, many contradictions were detected within the papers, so the classification of criteria and indicators posed significant challenges. The first conflict is a

conceptual paradox: to address criteria, different terms were used, such as "variables" (Shao et al., 2020), "criteria" (Xu & Yan, 2021), "dimensions" (Olaru et al., 2019), or "components" (Z. Li et al., 2019). We maintain that overcoming the conceptual confusion within TOD research is fundamental for advancing effective planning and evaluation practices. The term "criteria" is the most expressive, thus we selected it to represent TOD gages or standards. We also recommend it for future work.

The second contradiction is a limited alignment between criteria classification and TOD indicators. What highlights that little is known about the indicators' distribution among criteria. In this situation, common approaches of different papers are the presentation of a criterion as an indicator or applying a single indicator to calculate different criteria. For example, some researchers gauged the "quality of life" criterion with the indicator of "land use type" (Ma et al., 2018) or "compactness" (Xu & Yan, 2021). Also, compactness was considered an indicator of "density" or "mixed-use" (Lord et al., 2015), but other researchers connected it to "accessibility" (Nelson et al., 2015). Another example is articulating the built environment criterion differently among scholars. Some related it to "economic attractions" and "land use features" (Pan et al., 2017), while others considered it as a grasp of "design" (Furlan & Al-Mohannadi, 2020) or "walkability and accessibility"(W. Huang & Wey, 2019).

Therefore, we imply that TOD criteria are interrelated, but TOD literature should be structured. Every criterion must have its most paradigmatic indicator(s) following each city's characteristics and needs. Thus, extra studies shall investigate these enigmas to elucidate the criteria that most effectively articulate the fundamental principles of TOD.

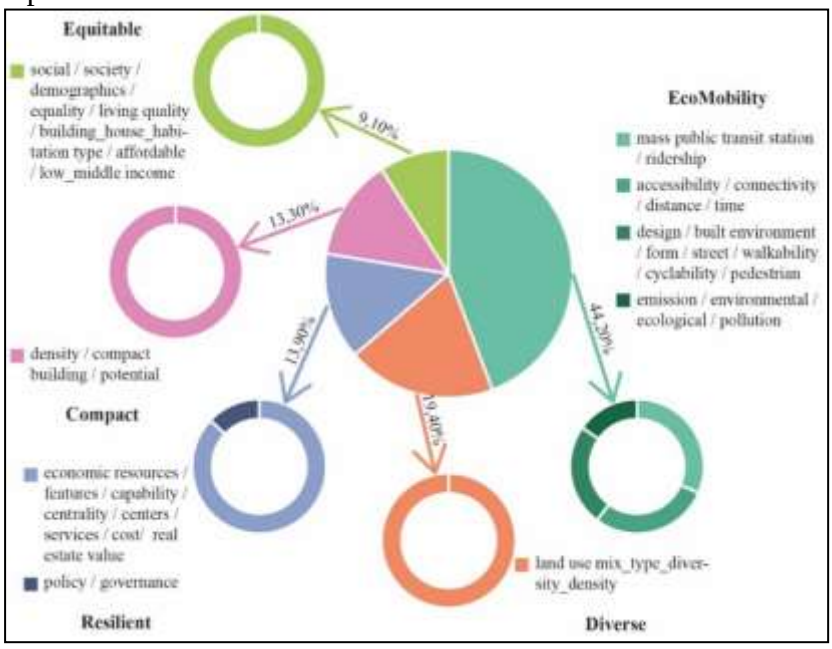
The third paradox is the large number of indicators used to represent criteria. In the 34 literature examined, we counted 471 indicators to gauge 214 criteria. This magnitude complicates the indicators' treatment and weighting, specifically subjective weighting (J. Liu et al., 2017).

A final conflict is that a single criterion or indicator was considered multiple times in the same study when other TOD criteria were neglected. For example, the transit criterion was considered three times when density was not mentioned in the case of (Z. Li et al., 2019). Furthermore, some criteria were expressed with several indicators while others were not, which can cause an overweighting of those criteria compared to the less expressed ones (J. Liu et al., 2017). For example, in (Singh et al., 2014), density was gauged and weighted with three indicators, while land use was assessed with a single indicator. Also (Su, Zhang, Wang, et al., 2021) assessed accessibility

with eight indicators, walkability with three, and two for serviceability.

There were also differences in the criteria ratios Figure N°, which conditions future TOD research to investigate the less mentioned: social aspects 9.10%, compactness, and resilient qualities, these both around 14%. Notably, 19.4% of the studies integrated diversity aspects, while EcoMobility principles were central to a substantial 44.2%. Those results indicate that place, transport, and sustainable mobility features of planning/assessing TOD have been well covered compared to the disregarded features, i.e. economic 12.1%, humanly, environment 6.7%, and policy 1.8%.

Figure N°5: Graph of the coding frequency identified in the topic Criteria.



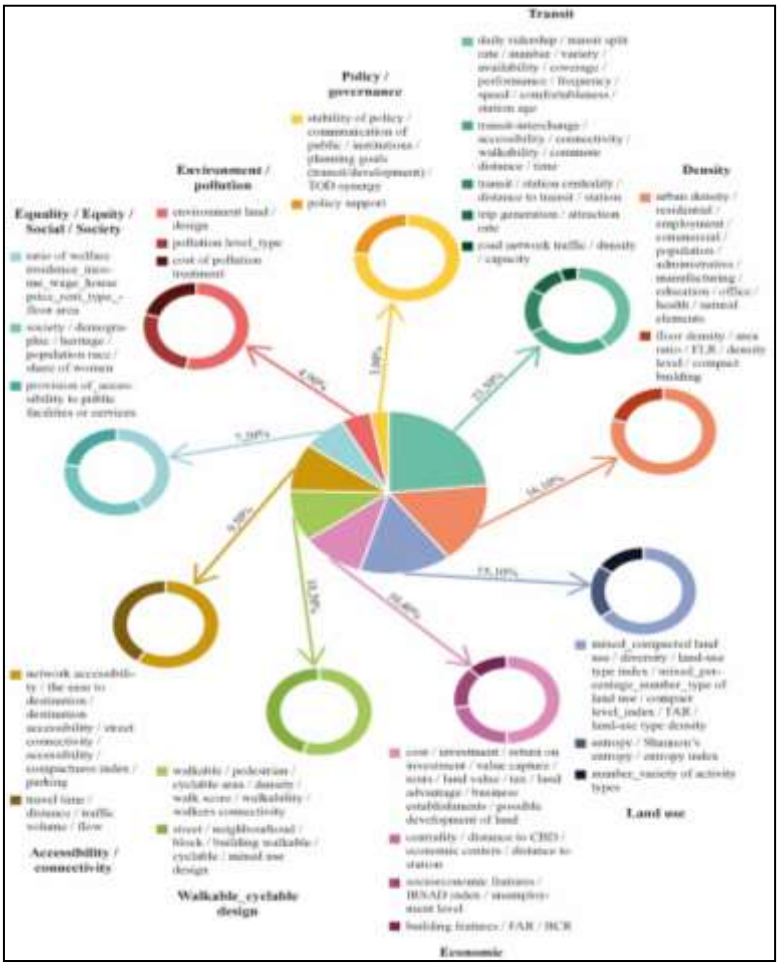
Source: The authors, (2020).

Regarding indicators, the results allowed us to distinguish which ones were frequently employed to express each criterion

Figure N°:. The ‘Transit’ category yielded the highest proportion with 23.5% of the mentioned indicators, with the ‘ridership/transit serviceability’ being its most stated indicator, with 9.5%. However, the most employed indicator overall is ‘urban densities’, with 12.8%. The most studied criterion does not maintain the most mentioned indicator, which fits perfectly

in our first-mentioned results: the criteria are not expressed adequately. Furthermore, social, environmental and policy are the least treated indicators, with each indicator comprising less than 8% of the total.

Figure N°:6 Graph of the coding frequency identified in the topic Indicators.



Source: The authors, (2022).

3.2. Analyses by continent

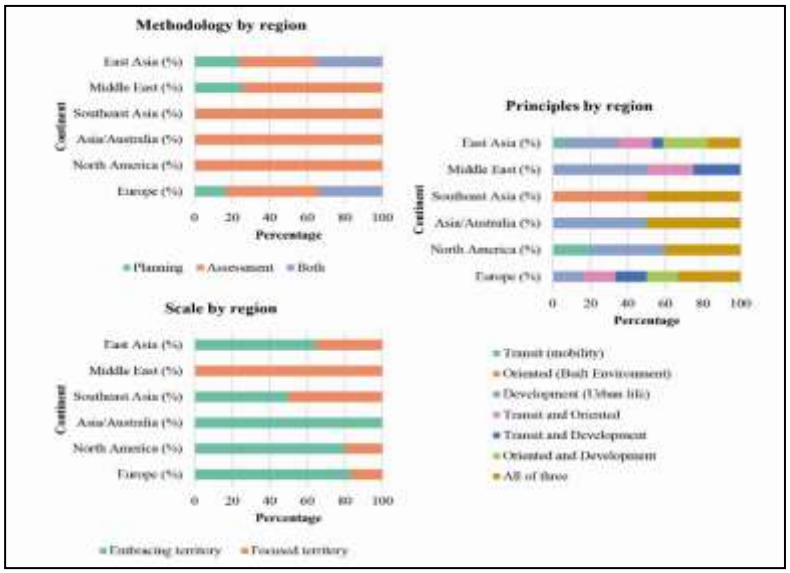
Analyses by continent are crucial since they provide a general vision of the orientation for the common approaches to assess/plan TOD in Latin American, African, European, North American, or Asian cities. Thus, it supplies researchers/planers with an inventory of

TOD planning/assessing tools, a perception of prospects for future research and the flaws that must be addressed.

To examine the findings related to location visually,

Figure N°: and Figure N° present graphs depicting the distribution of the five remaining topics across continents, considering the division of regions between developed and developing countries.

Figure N°:7 Graphs of the Methodology, Principles, and TOD Scale within the continent division.

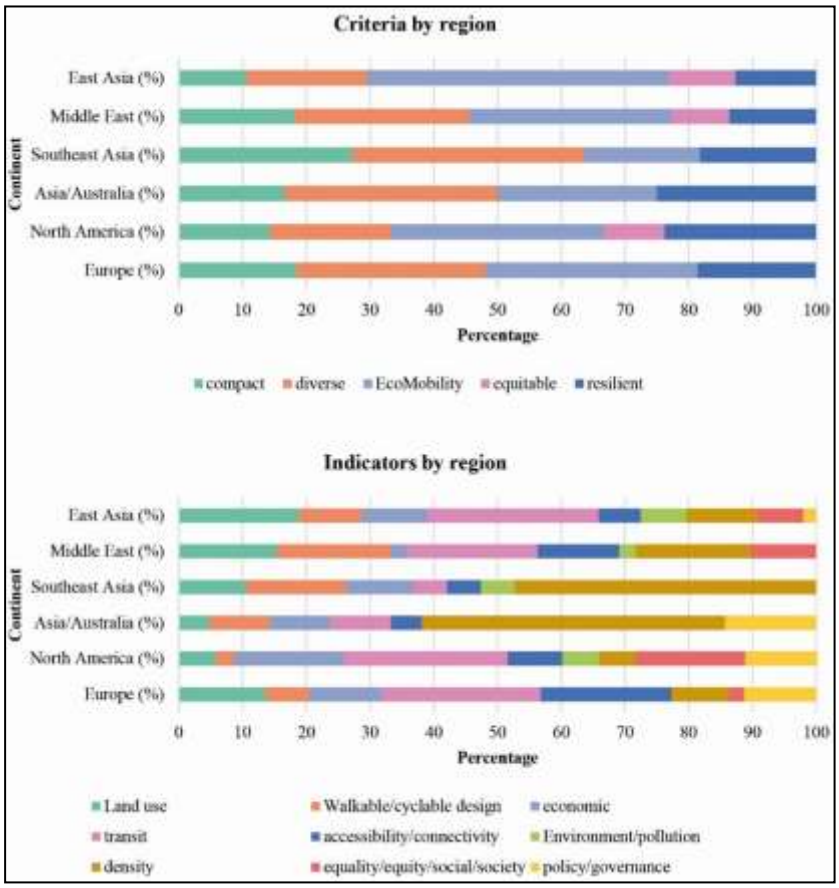


Source: The authors, (2022).

3.2.1. TOD methodology

When segregated by the continents, the methodologies used are more diverse in East Asia and Europe, with representative coding frequencies for every division associated. In contrast, Southeast Asia, North America and Asia/Australia only include studies in the category Assessment. At last, the Middle East maintains an insignificant variation between codes and categories.

Figure N° 8: Graphs of the Criteria and Indicators within the continent division.



Source: The authors, (2022).

3.2.2. TOD principles

Paralleling the methodology, East Asia and Europe locate studies diversified in the Principles topic among the three categories besides mixing them. Diversity decreases outside East Asia and Europe, despite scattered indication of mixing.

TOD Scale

Separating the scale per continent, we infer that in developed world studies focus on urban/regional and corridors/lines aspects. Conversely, studies located in the Middle East are directed to the Focused territory category, being the only region with studies dedicated to local scale. In Southeast Asia and East Asia, the mixture of all other TOD scales is substantial, thus involving not only the surroundings of stations but also a holistic perspective of the city and the corridors.

3.2.3. TOD planning /assessing criteria and indicators

Notoriously, North America, East Asia and the Middle East are the only regions that cover all the criteria categories, while social aspects remain mostly absent from studies concerning TOD planning and assessment in other regions. The EcoMobility criteria are the most mentioned in East Asia, North America, Europe, and the Middle East. In their turn, diversity criteria are the most considered in Southeast/Northeast Asia and Australia. Additionally, studies of the European continent highlight transit and accessibility/connectivity indicators, while environment indicators remain unstated. Moreover, North American studies arrange transit, economic and social indicators, while omitting the indicators of walkable/cyclable design. The Asian/Australian researchers disregard social and environmental indicators, while the density indicators are the most stated by 47.6%. For developing countries, the transit indicators are the most mentioned in the Middle East and East Asia literature, whereas Southeast Asia addresses density indicators by 47.3%. Furthermore, policy indicators remains insufficient in Southeast Asia and the Middle East, while their presence remains marginal in East Asia investigations, representing only 2%.

In generals, the standard deviation of the criteria and indicators ratio within all regions indicates the disparity in expressing and assessing TOD aspects in developed and developing countries, and signifies inconsistency in covering all TOD traits. Notably, in East and Southeast Asia for the criteria, when inconsistency of indicators is higher in Asia/Australia and Southeast Asia Table 1.

Table 1: Standard deviation of the criteria and indicators ratio by region

Region	Europe	North America	Asia / Australia	Southeast Asia	Middle East	East Asia
The standard deviation of the criteria ratio	13,0	9,2	12,6	13,5	9,4	15,7
mean criteria ratio	20,0	20,0	20,0	20,0	20,0	20,0
The standard deviation of the indicators ratio	8,0	7,5	14,5	14,5	7,7	7,4
mean indicators ratio	12,5	11,2	11,1	11,1	12,5	11,1

Source: The authors, (2022).

Conclusion

This paper interrogates the efficiency of TOD planning and assessment methodologies by investigating their inherent limitations from the initial articulation to the present day. The classification and coding analysis allowed a clear comprehension of what aspects are present in science. In essence, the majority of the 34 studies focus on TOD assessment, considering general aspects of urban development in embracing territories over transit lines. Regarding the topic of location, both developed and developing countries are treated, but a significant gap exists in research within the contexts of Latin America and Africa. Finally, for research of TOD measurement, criteria and indicators focused on issues like transit, density, and land use, putting aside social, environmental and policy aspects.

This review delves into the experiences and limitations documented in contemporary scientific explorations of TOD, contributing to a inclusive understanding of the field. Therefore, future research shall expand urban morphology and transit aspects, bringing more light to criteria that revolve around economic concentration (service poles, investments, offices), social aspects (wages, house type, race) and environmental impacts (energy, gas emission, noise pollution) so sustainability objectives would be addressed. Moreover, the number of indicators should be equal to each criterion, or at least better weighted, so that no criterion may gain importance over a less expressed criterion due to a lack of represented data by merging diverse weighting approaches and giving equivalent weights to each criterion and its representative indicators. For such reasoning, we also suggest that every criterion must have its most paradigmatic indicator(s) ensuing each city's characteristics and

needs. Thus, extra studies shall investigate these relations to define which criterion is the most expressive of each TOD principle for specific contexts. In addition, TOD measurement research should not focus on Urban and Transportation criteria separately and solely but also include criteria expressing the dynamic relation between transit forms and urban places (accessibility, connectivity and flows).

For the division designed over criteria and indicators, the proposed categories of this review stated in

Figure N°: and Figure N° reduced internal inconsistency compared to existing frameworks, permitting the assessment of TOD with fewer struggles between criteria or indicators. Therefore, we recommend employing them or similar ways in future work to cover all aspects of TOD without neglect. For a final suggestion, this review can instigate Latin American and African researchers to apply all these issues in their cities to expand TOD studies.

Because of the lack of literature access, we dismissed other databases, which may influence some results of this study, thus future works can extend to other databases for a complementary examination.

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