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Assessing maps for social topic representation: a qualitative content analysis of maps for sustainable mobility

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ABSTRACT

Cartographic representations are increasingly used to communicate sustainable mobility topics. Various formats of maps, such as static maps, mobile maps, map-based dashboards, story maps, and 3D map scenes, are created to illustrate mobility planning, traffic status, emissions, and travel behaviors. These maps are rich in cross-disciplinary information, target to diverse audiences, adopt various design technologies, and enable knowledge exchange among stakeholders of sustainable mobility. This paper examines how maps are used as communication tools for traffic and infrastructure to support decision-making and engage people to actively adapt their behavior towards green mobility. In this study, we (1) identified 48 maps that actively communicate sustainable mobility topics, (2) proposed a rigorous approach to assess maps that are created for communicating sustainable mobility topics, and (3) derived design recommendations for map makers to achieve more effective and efficient communication.

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Map; sustainability; mobility; content analysis; information visualization

RÉSUMÉ

Les représentations cartographiques sont de plus en plus utilisées pour communiquer sur les sujets de la mobilité durable. Plusieurs formats de cartes, tels que les cartes statiques, les cartes mobiles, les tableaux de bords basés sur des cartes, les story-map, les scènes 3D, sont créées pour illustrer la planification de la mobilité, l'état du trafic, les pollutions et les comportements de déplacement. Ces cartes sont riches en informations interdisciplinaires, destinées à divers publics, elles adoptent différentes technologies de conception et permettent l'échange de connaissances entre les parties prenantes de la mobilité durable. Cet article étudie comment les cartes sont utilisées comme outils de communication pour la gestion du trafic et les infrastructures pour aider à la prise de décision et inciter les gens à adapter leur comportement à la mobilité verte. Dans cette étude, 1/ nous avons identifié 48 cartes qui communiquent activement sur les sujets de la mobilité durable 2/ nous proposons une approche rigoureuse pour évaluer les cartes qui sont créées pour la communication de sujets sur la mobilité durable et 3/ nous avons déduis des recommandations de conception pour les cartographes pour obtenir une communication plus efficace et plus efficiente.

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1. Introduction

Sustainable mobility is a pressing issue in discussions about transitioning towards more environmentally friendly consumption and production. Sustainable mobility was firstly addressed by the European Commission and refers to '(sustainable mobility) should contain the impact of transport on the environment, while allowing transport to continue to fulfill its economic and social functions' (European Commission, 1992). Improving efficiency, shifting to green mobility, and reducing travel demands are three fundamental strategies to achieve this goal. Many stakeholders are involved in the implementation of the measures, such as policymakers, public transport operators, urban planners, travelers, and vehicle suppliers (Banister, 2008).

Translating mobility data into actionable decisions for a sustainable future is a complex process facing technical and social challenges. It requires contributions of experts and practitioners from different domains. For instance, organizing workshops to improve social awareness of sustainable mobility by involving citizens in public transport planning (Ibeas et al., 2011), improving infrastructure for clean mobility by optimizing locations of public electric charging stations (Shahraki et al., 2015), and providing data-based evidence for better policy-making towards a low-carbon freight system (Noll et al., 2022).

Thematic maps are often used to illustrate geospatial information such as transport and mobility data. With the proliferation of web and mobile technologies, digital, dynamic, and interactive maps are increasingly being designed to highlight geospatial objects, events, relationships, and phenomena. As aforementioned, sustainable mobility is a complex social and interdisciplinary scientific topic that requires joint efforts from multiple actors. Maps enable sustainable transportation policies to be displayed in practical applications, such as planning and designing transportation infrastructure. Maps provide accurate spatial information about cities and regions, providing critical data for planning and designing sustainable transportation infrastructure. For example, urban planners can use maps to determine the best road layout to optimize traffic flow and reduce congestion (Zhu et al., 2021). Furthermore, maps can be used to call for actions to achieve a sustainable mobility future, including improving urban planning for less travel (Abdelfattah et al., 2022), increasing the efficiency of transport systems (Fiore et al., 2019), evaluating policy instruments for sustainable transport (Diao, 2019), and encouraging citizens to participate in the design of sustainable public transport (Zegras et al., 2020).

Many digital mapping tools provide cartographic techniques as functions to handle spatial data, such as georeferencing, data classification, symbolization, generalization, and labeling. However, the expressiveness of maps depends much on the experience of map-makers and the mapping templates provided by computer software. Social topics that involve complex information and various stakeholders, such as sustainable mobility, require a vivid information presentation to ensure understandability and engagement. Despite the advantages that cartographic techniques offer, there is still a need for a comprehensive understanding of map functions in the context of sustainable mobility.

The goal of this study is to enhance the potential capabilities of thematic maps in communicating multi-faceted social topics. We focus on assessing maps designed to support sustainable mobility topics because of challenges to (1) design the maps that not only represent data but lead to actions towards sustainability, (2) effectively use various mapping techniques to support information communication, and (3) ensure the visual interface is intuitive to understand. We set three objectives: to identify recently created maps in support of sustainable mobility, to propose a rigorous approach to assess maps, and to share experiences and lessons for future thematic map-making. In this study, we aim to bridge this gap by systematically assessing 48 maps that included in 16 applications and reports for sustainable mobility topics. We developed a framework to summarize the state of the art in mapping creation methods and provide design recommendations.

2. Related work

2.1. Visual literacy and map communication

Visualizations provide a space for creative expression of ideas and information. They are received by audience through an understanding of signs and symbols, a sense of aesthetics, professional skills, and visual literacy (Moriarty, 1997). Effective and efficient visual communication is dependent on the 'aesthetic triad', which is viewed as a combination of three interactions with sensory-motor, emotion-valuation, and knowledge-meaning (Vartanian & Chatterjee, 2022). The potential functions of visualizations are operated threefold, including *what* is represented, *how* perceptual and emotional experiences are presented, and *how* the viewer is positioned in terms of mood and attitude (Riley, 2024).

Maps and geovisualizations are created to convey geospatial information from the author to readers. Nowadays, the process of creating maps is simplified with the help of digital tools with predefined mapping functions, such as accessing base maps, georeferencing, choosing suitable color schemes, and providing interactions like zooming and panning. The technique mature has enlarged social participation in spatial information communication with maps (Steinmann et al., 2005). For example, a map-based mobile application was provided to collaboratively communicate accessibility issues in a city (Shigeno et al., 2013) and a map-based web application was created for participatory consultation on a neighborhood revitalization plan (Pánek, 2018).

Thematic maps are increasingly being designed by non-cartographers with the aid of digital mapping tools, especially in geo-related domains, such as urban planning, transport planning, and traffic management. For instance, dot maps and geographic heat maps were used to show the temporal change of urban areas (Liu et al., 2020), choropleth maps were used to represent the accessibility of public transportation in transport planning (Allen & Farber, 2020), and animated maps were used to show the vehicle flow (Akhter et al., 2020).

Communicating geospatial information through maps seems to be a trivial task, including encoding information by the map makers and decoding the information by the map users. However, much 'noise' is involved along this information chain, as the designing and interpretation of map symbols may be influenced by human interaction and experience with maps (Robinson & Petchenik, 1975). With the increasing use of digital map-making tools, computer programs may influence the initiation of map design. Therefore, assessing the expressiveness of these maps is crucial to provide valuable recommendations for the future of the map-making industry.

2.2. Content analysis of map and geovisualization

Content analysis is widely applied as a systematic and replicable method for distilling large amounts of text and visualizations into a few characteristics (Stemler, 2000). Considering that sustainable mobility maps often encode (big) mobility data into interactive graphics, content analysis of sustainable mobility maps should extend to data and new media. Data physicalization is an emerging field that uses tangible materials to encode data, which partly overlaps with creating maps with digital tools. In this section, we jointly analyze the codebooks in the fields of data physicalization and cartography.

The previous studies provided important benchmarks to evaluate the visualizations because they outlined what factors were important in the visual communication of information. We listed three codebooks for data physicalization and four codebooks for thematic mapping to understand the scope of factors. Although each codebook used different terms, we summarized the factors into seven categories as shown in Table 1.

For domain-specific data representation, having an overview of the included attributes is important. Three codebooks included *theme* to gain an overview of what attributes of certain topics are represented (de Sherbinin et al., 2019; Fish & Calvert, 2017; Verena et al., 2023). *Context* embeds the data representations to a social framework of a specific topic, such as task, audience, and intent. Bae et al. (2022) included it in their codebooks to examine how the context guides the designs. *Data* is the raw material in data-driven representations and the codebooks included examined nature of data, such as the number of variables (Verena et al., 2023), analytical methods (de Sherbinin et al., 2019), data type (Bae et al., 2022; Ranasinghe & Degbelo, 2023), and data uncertainty (de Sherbinin et al., 2019). All the listed codebooks included *representation* to understand how the specific themes were reflected in the sensory representations. Maps are unique artifacts that encode data and guide viewers' visual attention to the key information of spatial data. Analyzing the map elements can help examine the effectiveness and efficiency of maps as an instrument of information communication. Many cartographic methods, such as map layout, symbolization, generalization, color, scale, and dimension, are analyzed in map representations (de Sherbinin et al., 2019; Fish & Calvert, 2017; Muehlenhaus,

Table 1. Summary of analysis categories of existing codebooks for maps and visualizations.

	Analysis categories						
Codebook	Theme	Context	Data	Representation	Interactivity	Devices	Usability and perception
Persuasive maps (Muehlenhaus, 2013)				✓			
Solar energy maps (Fish & Calvert, 2017)	✓			✓	✓		
Climate vulnerability maps (de Sherbinin et al., 2019)	✓		✓	✓			✓
Multi-sensory Analytics (McCormack et al., 2018)			✓	✓		✓	✓
Data physicalization (Bae et al., 2022)		✓	✓	✓	✓	✓	
Temporal data visualization (Verena et al., 2023)	✓		✓	✓	✓		✓
Data physicalization (Ranasinghe & Degbelo, 2023)		✓	✓	✓		✓	✓
Sum	3	2	5	7	3	3	4

2013; Verena et al., 2023). Interactivity is often used in modern data representations to provide more details and abstract information on demand. Three codebooks included interactions, such as import, export, overlay, pan, zoom, filter, search, calculate, select, and annotate (Bae et al., 2022; Fish & Calvert, 2017; Verena et al., 2023). *Device* is often discussed in codebooks in the field of data physicalizations. It shows the veriaties of visualization and interaction methods enabled by different technologies for data representation. Last but not least, *usability and perception* are addressed in four codebooks to examine the performance of designs from the users' perspective.

In summary, the codebooks from both fields of cartography and data physicalization include visual representation in their content analysis. Codebooks of maps mainly focus on the map content such as symbol design, theme, data, and interactivity. While codebooks on data physicalization focus more on context, device, usability, and perception.

3. Methodology

To gain an overview of the maps for sustainable mobility, we conducted a content analysis of existing maps. We first collected map made for sustainable mobility communication using a keyword-searching approach and then iteratively designed a codebook as a reference to evaluate the maps. The codebook was proposed by adopting previous codebooks mentioned in Section 2 and in consideration of ethical issues in the map-making process. The coding process was conducted independently by two of the authors. The results then served to summarize the status quo of maps for sustainable mobility communication and propose design suggestions.

3.1. Map collection

To conduct the survey in a broad range, we collected 30 tools and articles related to sustainable mobility topics from the research and implementation fields. The sources were (1) Google Search and Google Image Search with keywords, (2) Google Scholar Search with keywords. The searching keywords were related to sustainable mobility, such as 'sustainable traffic dashboard', 'sustainable mobility map', and 'digital twins and sustainable mobility'. Following the searches, a set of filters were applied to find the relevant and typical examples. Firstly, the sample should include sustainable mobility as its major topic. Secondly, the sample should use map(s) as the major communication instrument. Thirdly, the maps should be legible, and descriptive text about the map should be available. Last but not least, we strived to cover a wide range of application fields and design styles. Thus the samples that shared too many similarities were excluded. The iterative map collection lasted three months from September 2023 to November 2023. A total of 48 maps were identified and they were selected from 16 valid records. Figure 1 shows the workflow of the map selection process.

Although not many maps were deliberately created for the topic of sustainable mobility, our samples cover a wide range of practices. In Figure 2, we show seven representative maps that communicate sustainable mobility topics through a mobile application, a report, a story map, a web tool, a dashboard, an art map, and a 3D city model. They were created by various organizations and are supposed to be used across different display devices.

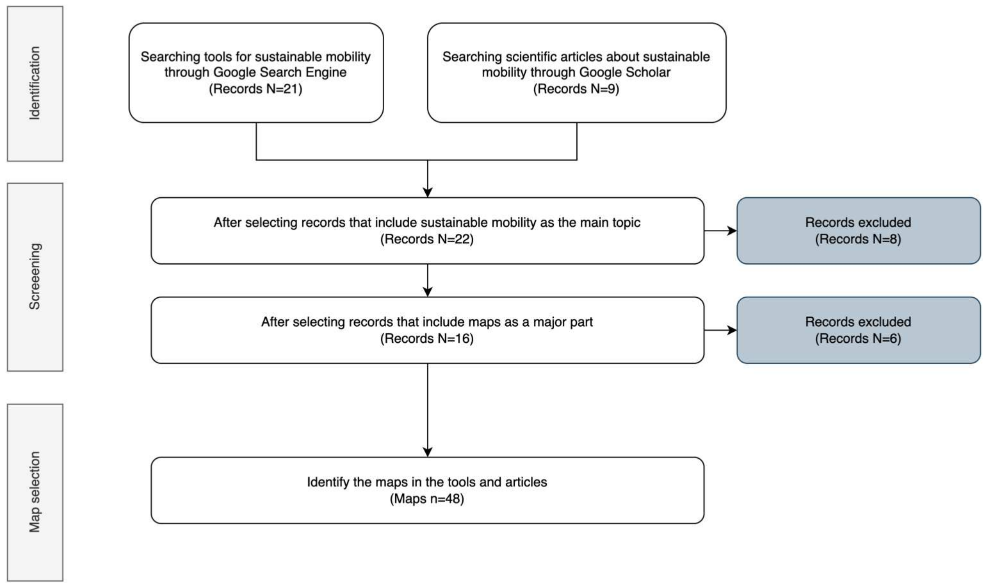

Figure 1. A three-phase workflow for identifying maps of sustainable mobility.

3.2. Codebook

We proposed a codebook as a reference for the content analysis of the sustainable mobility maps. The codebook consists of five categories that examine the key factors of maps reflected in five questions: *What is the context of sustainable mobility considered in map making*? *What factors are important to represent*? *How are sustainable mobility topics reflected on maps*? *What data is related to representing the sustainable mobility topics*? *How do maps support the communication among the diverse stakeholders of sustainable mobility*? *How well are the maps designed to express the intended information*? In this study, we proposed 22 dimensions related to *theme*, *context*, *data*, *visual design*, and *visual richness* to reflect the current state of map design as shown in Table 2.

Context. It describes the social framework of a map for sustainable mobility. It grounds the ways a map serves as an instrument of information communication (Peterson et al., 2023). This category considers the *intent* (what is the functional purpose of the map), *provider* (who initialized the map to serve sustainable mobility), *audience* (who are the target receiver of such information carried in maps), and *implication* (which format do the maps embedded in). The contextual information is mostly available in the text that describes the application or in the article.

Theme. It outlines the perspectives addressed by map makers to approach sustainable mobility. This study considers three dimensions: (1) Categories of the *approaches* for sustainable mobility. It mainly falls into two groups, understanding the current situations of *traffic*, *transport emissions*, *infrastructure*, *policy impact*, and *travel demand*, and calling for actions to reduce the emission by *improving infrastructure* with the aim to improve travel efficiency and reduce trips and *encouraging clean travel mode* as an alternative choice. (2) *Transport mode* is a key factor in sustainable mobility, because different approaches should be applied specifically to different transport modes. In this codebook, we identify

Figure 2. Some of the selected maps created for communicating sustainable mobility: (a) A user interface of a mobile application to encourage alternative travel modes, (b) a map showing the pedestrian flow from a public sector report, (c) a part of a story map made by an intergovernmental organization to show the CO2 emissions from road transport, (d) a web-based tool made by a private company to assist accessibility analysis of green transport modes, (e) a dashboard made jointly by a government and a company to monitor the traffic, (f) a art map illustrating urban design guideline by an intergovernmental organization, and (g) a 3D scene showing the traffic flow with the urban infrastructure.

the illustrated *transport modes* on maps. (3) Evaluation of whether a map *focuses* on showing the *overview* of sustainable mobility topics or depicting an *individual* travel history. It may influence the selection of cartographic methods for showing different perspectives.

Data. It is the raw material of maps. Describing data can provide an understanding of its nature and promote a better selection and use of data in the future. We examine the data in terms of *source*, *geography*, *time*, and *transformation*. These dimensions can help in

Table 2. The codebook for analyzing sustainable mobility maps with 22 dimensions.

Design Dimension	Code
Context	
Intent	Persuasion, Recommendation, Monitoring, Planning
Provider	Private Sector, Public Sector, Research & Education Institute
Audience	Researcher, Public, Planner
Implication	Dashboard, Storymap, Article, Application, Game, Animation
Theme	
Approach	Understand Traffic, Understand Transport Emissions, Understand Infrastructure, Understand Policy Impact, Understand Travel Demand, Improve Infrastructure, Encourage Clean Travel Mode
Transport Mode	Foot, Bike, Scooter, Car, Public Transport, Ridesharing, Airplane, General
Focus	Individual, Overview
Data	
Source	Open, Not Open, Both, No Data
Geography	General, Specific
Time	Past, Present, Future
Number of Variable	Numeric
Transformation	Descriptive Statistics, Algorithm, Simulation, No Transformation
Visual Design	
Map Type	Choropleth Map, Trajectory Map, Line Feature Map, Proportional Symbol Maps, Dot Map, Density Map, Art Map, 3D Scene
Cartographic Process	Simple, Fair
Textual Element	Sufficient, Insufficient
Interactivity	Search, Filter, Self-update, Static
Visual Richness	
Color Mean	High, Moderate, Low
Color Standard Deviation	High, Moderate, Low
Color Skewness	High, Moderate, Low
Entropy	High, Moderate, Low
Magnitude Slope	High, Moderate, Low
Fractal Dimension	High, Moderate, Low

understanding what data is represented on maps under the sustainable mobility context. In this study, we assess the data source from *open* or *not open* to understand the importance of different data sources. We analyze whether the maps include geographic *specific* or *general* data. We measure the time coverage of data, which means we regard the historical data as *past*, the real-time or near real-time data stream as *present*, and predicted or simulated data in future scenarios as *future*. We then count the number of variables by measuring the attributes from the legends of the maps. *Transformation* includes four metrics, *descriptive statistics* refers to the numeric summary that gives the inductively describe the datasets, such as the sum of vehicles and spatial hotspots, *algorithm* refers to the process of data, such as interpolation and prediction of travel demand, *simulation* refers to the mathematical modeling of transportation systems.

Visual design. The rich cartographic styles are often applied to efficiently express spatial information (Kent & Vujakovic, 2011). We include *map type*, *cartographic process*, *textual element*, and *interactivity* to analyze how cartographic methods are used to represent sustainable mobility topics. We identify eight commonly used map types in mobility topics, for instance, *trajectory map* refers to the maps showing the path of moving objects, *line feature map* refers to the maps showing streets or railways. *Cartographic process* assesses whether a map adopts generalization methods, such as aggregate, reclassify, and symbolization, to ensure good readability of geographic features. *Textual element* is included to examine whether the title, legend, data source, and other textual map elements are sufficient to help map readers understand the information. *Interactivity* is often embedded in digital maps to show spatial information on demand. We identified the four common types of interactions used in sustainable mobility maps, i.e. *search*, *filter*, *self-update*, and *static*.

Visual richness. The visual appearance of maps influences spatial information perception and pleasure (Gartner, 2019). We attempt to describe the visual features of the maps and use the well-established image feature extraction methods. In this study, we choose *mean*, *standard deviation*, and *skewness* to index the colors used in maps (Mutlag et al., 2020). We use *entropy* to describe the visual complexity of maps (Schnur et al., 2018). In addition, we measure *magnitude slope* as the logarithmic slope of the radially averaged Fourier magnitude and *fractal dimension* using the Minkowski-Bouligand box-counting method to reflect the beauty of the map graphic (Forsythe et al., 2011; Lakhal et al., 2020). To have a better understanding, we further compare the quantitative features between maps specifically designed for sustainable mobility and thematic maps made for transportation. We selected 45 thematic maps for transportation made by professional map makers from an open dataset for maps (Yang et al., 2023). The extracted features from the thematic maps were used as a reference. The extracted features of a map for sustainable mobility were labeled as *low* if the value is less than the first quartile of the reference maps, *moderate* if the value is between the first quartile and the third quartile, or *high* if the value is greater than the third quartile.

The coding procedure was conducted iteratively. It began with two authors independently coding the maps using a preliminary codebook. The coding of maps was conducted in three rounds and the codebook was refined after each round. In addition, the authors discussed the codes with domain experts. Finally, the reliability of the codebook is examined using Krippendorff's alpha (Krippendorff, 2004) with a high agreement ($\kappa = 0.96$).

4. Results

In this section, we assess the sample maps following the proposed codebook and show the results in tables.

4.1. Context

We analyzed the context of each collected record. Although each record contains multiple maps, the maps share the same context as *provider*, *audience*, *intent*, and *presentation*. The assessment results of the context of records are illustrated in Table 3. Most of the applications and reports were initialized by the *public sector* (n =10) and sometimes collaborated with the *private sector* (n =3), the *private sector*, and *research & educational institutes* contributed three records respectively. Most samples were targeted to the *planner* (n =9) and the *public* (n =6), and only one was targeted to *research* use. The samples were created with various *intents*, *monitoring* (n =5), *planning* (n =5), *persuasion* (n =4), and *analysis* (n =2). The formats of the samples were diverse, including four *dashboards*, 5 *applications*, 4 *articles*, one *animation*, one *game*, and one *story map*. Among them, dashboards were mostly made by the private sector for monitoring, articles were written for planning and analyzing purposes, and applications and games were made to encourage the public to adapt their transport choices for the sustainable mobility.

Table 3. The context of using maps to communicate sustainable mobility.

	Provider			Audience			Intent				Presentation					
ID	Private Sector	Public Sector	Research	Public	Planner	Researcher	Monitoring	Planning	Analysis	Persuasion	Article	Application	Dashboard	Story map	Game	Animation
R1 (Voi, 2021)	■			■						■		■				
R2 (SIMETRA, 2022)	■				■		■						■			
R3 (Heimerman, 2022)	■	■		■			■						■			
R4 (Andy Zheng, 2022)	■				■		■						■			
R5 (Vijverberg, 2019)	■	■			■		■						■			
R6 (Urquijo, 2018)	■			■						■		■				
R7 (Fjollë Caka, 2021)		■			■			■			■					
R8 (Farella et al., 2020)			■	■						■					■	
R9 (Ana Florina Pirlea, 2023)		■		■						■				■		
R10 (Lesley Macinnes, 2020)		■		■				■			■					
R11 (Elias Pajares, 2021)	■				■			■				■				
R12 (Benjamin Büttner, 2022)			■		■			■			■					
R13 (Yeon et al., 2023)			■			■		■								■
R14 (Janne Rinne, 2022)	■	■			■		■					■				
R15 (LIDA, 2020)	■				■				■			■				
R16 (Joost Adorf, 2022)	■				■				■			■				
Sum	10	7	3	6	9	1	5	5	2	4	3	6	4	1	1	1

4.2. Theme

We analyzed the *theme*, including *intent*, *transport mode*, and *focus*, of each collected maps and showed the results as a bar chart in Figure 3. More than half of the collected maps (n =29) aimed to help readers understand the current state of mobility and the reminder (n =19) were calling for actions to achieve sustainable mobility. A large share of the maps depicted the transportation modes such as bike (n =18), public transport

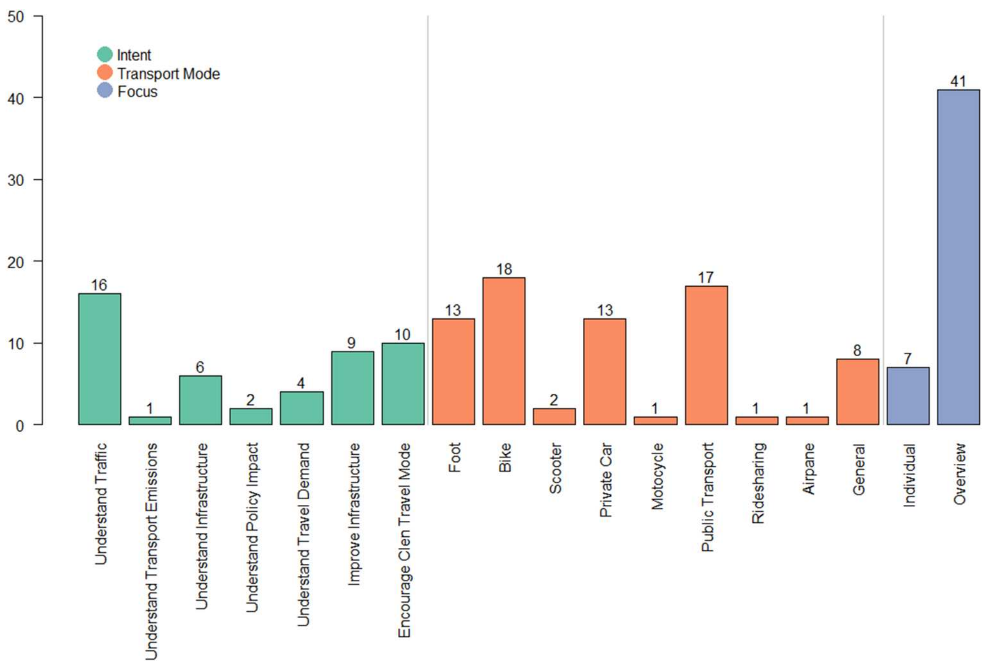

Figure 3. The summary of the theme, including *intent*, *transport mode*, and *focus*, of the collected maps for sustainable mobility.

(n =17), foot (n =13), and private car (n =13). A not inconsiderable amount of the maps (n =8) showed measures that were generally applicable to all the modes. In addition, most maps (n =41) provided overviews (n =41) and seven maps focused on presenting individual travel histories.

4.3. Data

We analyzed the *data* regarding the *source*, *geography*, *time*, *transformation*, and *variables* illustrated on each map. As shown in Table 4, most of the sample maps utilized open data

Table 4. The assessment of data used in maps for sustainable mobility.

	Source		Geography		Time			Transformation				Variables
Map ID	Open	Not Open	General	Specific	Past	Present	Future	Descriptive Statistics	Algorithm	Simulation	No	Number
R1-M1		■	■		■			■				6
R1-M2		■	■			■		■				1
R2-M1		■		■		■		■				2
R2-M2		■		■		■		■				4
R3-M1	■	■		■		■		■				11
R4-M1		■		■		■		■	■			9
R4-M2		■		■	■			■				4
R5-M1	■			■		■		■				9
R6-M1		■	■		■			■				4
R6-M2		■	■		■			■				2
R7-M1	■			■			■	■			■	8
R7-M2	■			■	■			■				1
R7-M3	■			■	■			■				1
R7-M4	■			■	■			■				8
R8-M1		■	■				■	■			■	1
R9-M1	■		■		■			■				1
R9-M2	■		■		■			■				1
R9-M3	■		■		■			■				3
R9-M4	■		■		■			■				1
R9-M5	■		■		■			■				1
R10-M1	■			■	■			■				6
R10-M2	■			■	■				■			9
R10-M3	■			■			■		■			3
R10-M4	■			■			■		■			12
R10-M5	■			■			■		■			4
R11-M1	■		■		■				■			1
R11-M2	■		■		■				■			1
R11-M3	■		■		■				■			1
R12-M1	■		■				■				■	1
R12-M2	■		■				■				■	1
R12-M3	■			■	■			■				1
R12-M4	■			■			■				■	1
R12-M5	■			■			■				■	6
R12-M6	■			■	■				■			5
R12-M7	■			■	■				■			2
R12-M8	■			■			■		■			5
R13-M1	■			■	■					■		4
R14-M1	■			■		■		■				2
R14-M2	■			■	■						■	1
R15-M1	■	■		■	■						■	1
R15-M2	■	■		■	■						■	1
R15-M3	■	■		■	■			■				2
R15-M4	■	■		■	■			■				4
R16-M1	■	■	■		■						■	1
R16-M2	■	■	■		■			■				1
R16-M3	■	■	■		■			■				1
R16-M4	■	■	■				■	■				5
R16-M5		■	■		■			■				2
					Sum							Median
48	38	19	20	28	30	7	11	27	11	1	10	2

provided by companies or governments. Some maps used the open data as base map and showed displayed personal travel histories to encourage the public to take action for sustainability. Some maps were created as analytical tools for people to show spatial patterns of mobility data regardless of the data source. 20 maps were made for general geographic area and 28 maps for specific areas. Furthermore, a majority of the sample maps (n =30) used data from the past, seven maps used present data, and eleven maps displayed the data for future scenarios. In many cases, data was preprocessed, and then mapped to ensure an good interpretation of the spatial patterns. Among the selected sample, 24 maps used descriptive statistical methods to summarize metrics, e.g. the number of buses and parking spots, the spatial hotspots; 14 maps used algorithms to calculate the accessibility and walkability; 10 maps plotted the raw data without preprocessing, and one map showed the simulated data. Most maps illustrated one or two variables, and some of the maps composed of multiple variables, such as R4-M1 of nine and R10-M4 of 12.

4.4. Visual design

We assessed the visual design of the collected maps in *map type*, *interactivity*, *cartographic processing*, and *textual element*. The results are shown in Table 5. Among the 48 collected maps, various map types were used, especially choropleth maps were used to show such as walkability and accessibility, dot maps and trajectory maps were used to represent the traffic flow. More than half of the samples were interactive maps. It is worth noticing that most static maps included cartographic processes and provide sufficient textual elements. While interactive maps mostly displayed raw data, such as dots, trajectories, and line features without sufficient map design elements, e.g. symbols, aggregation methods, titles, legends, and necessary textual descriptions.

4.5. Visual richness

We evaluated the visual richness of sample maps using thematic maps for transportation as a benchmark. The results are shown in Figure 4. The *mean* shows that a lot of sample maps used either much darker colors or much brighter colors than benchmark maps. The *standard deviation* shows that compared to benchmark maps, many sample maps used similar colors or very diverse color schemes. The *skewness* shows that the distribution of colors was in general darker. The *entropy* of sample maps were higher than that of benchmark maps, which means the sample maps contained more different color levels. Most of the values of *magnitude slope* is moderate and high, which indicates that there were more details and contrast between foreground and background in sample maps. It aligns with many sample maps that did not include cartographic generalization processes. The *fractal dimension* shows the shape of depicted objects in sample maps are polarized, either more complex or much simpler than benchmark maps.

5. Recommendations and future directions

Graphicacy enriches human perception of spatial information along with literacy and numeracy. With the advantage of intuitiveness, maps are increasingly taking on the

Table 5. The assessment of visual design in maps for sustainable mobility.

	Map Type								Interactivity				Cartographic Processing		Textual Element	
Map ID	Choropleth Map	Trajectory Map	Line Feature Map	Proportional Symbol Maps	Dot Map	Density Map	Art Map	3D Scene	Search	Filter	Self-update	Static	Simple	Fair	Sufficient	Insufficient
R1-M1					x						x		x		x	
R1-M2					x						x		x		x	
R2-M1					x						x		x			x
R2-M2					x						x		x		x	
R3-M1		x							x		x			x	x	
R4-M1					x					x	x			x	x	
R4-M2			x								x		x		x	
R5-M1					x						x			x		x
R6-M1		x									x		x		x	
R6-M2		x									x		x		x	
R7-M1							x					x		x	x	
R7-M2			x									x	x		x	
R7-M3			x									x	x			x
R7-M4							x					x	x	x		x
R8-M1		x									x			x		x
R9-M1	x								x					x	x	
R9-M2	x											x		x	x	
R9-M3	x			x								x		x	x	
R9-M4	x									x				x	x	
R9-M5	x									x				x	x	
R10-M1				x								x		x	x	
R10-M2	x				x							x		x	x	
R10-M3	x											x		x	x	
R10-M4	x				x							x		x	x	
R10-M5	x			x								x		x	x	
R11-M1					x				x				x		x	
R11-M2	x								x				x		x	
R11-M3	x								x				x		x	
R12-M1							x					x		x		x
R12-M2							x					x		x	x	
R12-M3					x							x		x	x	
R12-M4			x									x		x		x
R12-M5							x					x		x		x
R12-M6			x									x		x	x	
R12-M7	x											x		x	x	
R12-M8	x											x		x	x	
R13-M1					x						x		x			x
R14-M1								x			x		x			x
R14-M2								x				x	x			x
R15-M1					x							x	x			x
R15-M2					x							x	x			x
R15-M3						x				x			x		x	
R15-M4						x			x	x			x		x	
R16-M1			x									x	x			x
R16-M2	x											x		x		x
R16-M3				x		x						x		x		x
R16-M4		x							x					x		x
R16-M5								x		x				x		x
Sum																
48	14	5	6	4	13	2	5	3	7	6	13	25	20	28	30	18

role of communicating social topics that have spatial components. The codebook helped us to assessment of the collected maps in an unified procedure. It reveals how maps can highlight the spatial information within the framework of communication of sustainable mobility. The results gives an overview of the roles of maps in showing *what*, *how*, *who*, and *to whom* under the topic of sustainable mobility. This codebook highlighted the sustainable mobility topic, especially in *Theme*. As a representative social topic, sustainable mobility needs to be coordinated across multiple social

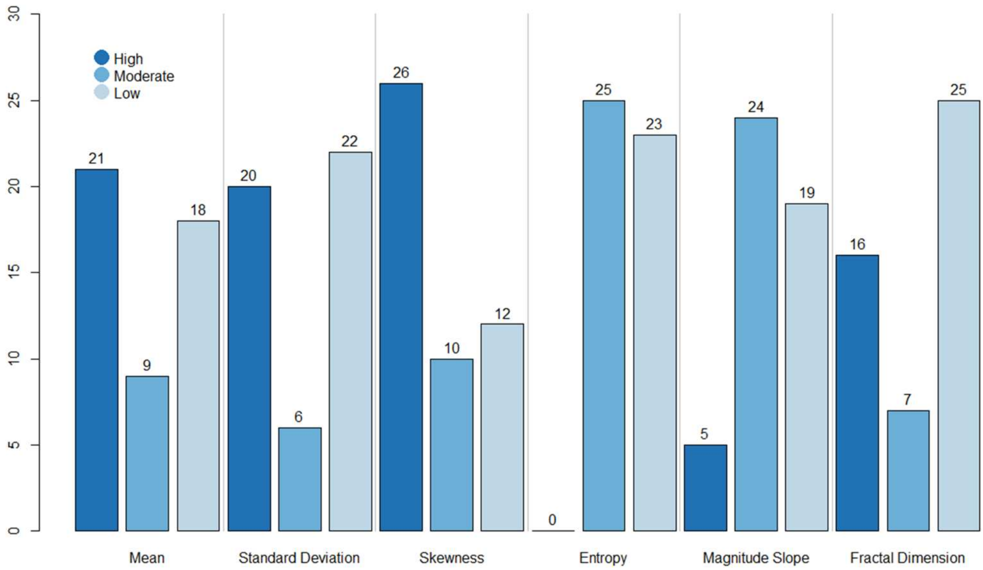

Figure 4. The bar chart shows the visual richness features of sample maps in comparison to benchmark maps.

sectors and an increasing number of maps are being made to convey the complex spatial information of mobility to diverse stakeholders. According to the results shown in Section 4, this study provides the following suggestions for map design to serve for achieving sustainable mobility.

Context. Many digital maps were created to facilitate decision-making in favor of sustainable mobility, such as mode choice. Increasingly private sectors are providing map-making tools with templates, such as the Sample Map R6 (Urquijo, 2018), R13 (Yeon et al., 2023), and R14 (Rinne et al., 2022), so that non-cartographers could load their mobility data to visualize the geospatial locations and patterns. To increase the engagement of such map-based applications, we recommend that designing maps with more interactions, such as story maps and ramifications as R8 (Farella et al., 2020).

Theme. Achieving sustainable mobility requires a change to the past status. Therefore, map-making for this topic should consider more of calling specific actions and showing the differences caused by the changes. For example, it shows reduced air pollution by using public transportation rather than private vehicles, such as the Sample Map R7 (Caka et al., 2021), and compares the traveling demand with improved infrastructure plans. In addition, more maps should be made in consideration of 'slow mobility', such as foot, scooter, and wheeling in Sample Map R3 (Heimerman, 2022), R6 (Urquijo, 2018), and R7 (Caka et al., 2021).

Data. With the ever-increasing amount of data, future challenges in visualizing mobility data involve protecting privacy regarding human mobility data and ensuring trustworthiness. More maps should be made to integrate the open data and private data to optimize the data-driven insights. For example, the Sample Map R3 (Heimerman, 2022) and R5 (Vijverberg, 2019) integrated data from various service providers. Most of the sample maps used data from past, some of them show the predicted mobility data, but only a few used real-time or near real-time data. The data from different time period can be integrated within one map, so that map readers can have a better understanding of the mobility under different scenarios and maybe lead to changes to their travel decisions. Real-time data preprocessing, aggregating, and analysis should be improved for a deeper understanding of the traffic events.

Visual design. With the help of digital mapping tools, producing maps becomes easier for amateur map makers. Trajectory and line maps are often used to show the mobility data. However, we noticed the art maps benefit to show the mobility plans and impact to transportation. They can help transportation designers to express better the spatial related plans and visions, such as the Sample Map R12-M1 (Büttner et al., 2022), thus should not be ignored in the future. In addition, many interactivities were provided by the maps for map readers to explore detailed information. However, many of the digital tools did not highlight the importance of data preprocessing and textual elements, so that many maps were made with limited expressiveness.

Visual Richness. The sample maps differed to the traditional static maps made for transportation. There is an tendency that the sample maps were projecting the measured data onto basemaps, such as the location of vehicles, but not providing sufficient contextual spatial information such as road types and buildings, such as the Sample Map R7-M2 (Caka et al., 2021) R13 (Yeon et al., 2023).

In summary, we have the following suggestions to improve the potential of the expressiveness of maps made for sustainable mobility:

- Improve logical design of symbology, classification, grouping, simplification, and color scheme selection
- Provide sufficient and appropriate titles, legends, and descriptions for map readers to understand the meaning of the represented information
- Provide the information about data sources and data processing methods to ensure transparency
- Providing annotation functions so that the users can add and share their own ideas
- Provide comparative views of different scenarios for decision and policy-making
- Provide charts and text along with the maps to give the audience multiple perspectives to understand a topic
- Reduce the cognitive load on map readers by de-emphasizing irrelevant geographic features
- Incorporate multi-media technologies, such as 3D visualization, augmented reality, and virtual reality to show the data with rich interactivity

6. Conclusion and outlook

Maps are no longer just a combination of technology and artistic design, but an open space to foster social dialogs among individuals and organizations. This study assessed maps for the communication of sustainable mobility topics. We reflected on the current map designs and the gaps, and identified the fact that maps are being increasingly used in spatial information communication. Our recommendations derived this study serve to proactively narrow the gaps in knowledge and techniques for mapping sustainable mobility topics.

This study showcased the recent development in a cross-disciplinary field and coherently considered 22 design dimensions in theme, context, data, visual design, and visual richness. We combined the paradigm of map use space (MacEachren, 1994) and attempted to incorporate it with design aesthetics (Fabrikant et al., 2012; Ortag, 2009) and to study maps as communication tools for a social topic. Since sustainable mobility is an emerging social topic, there are not many maps available. Nonetheless, we iteratively selected 48 sample maps from 16 applications and reports created by different organizations and made for different communication purposes. In addition, we proposed the codebook, which can be further used to assess maps designed for communicating social topics.

There are some limitations of this study. The map design process of the samples remained unknown and not easy to infer from the maps as design results. Moreover, how the maps are used in reality and how people like them are inaccessible to the authors. In the future, it is necessary to evaluate the usability and user experience with the end users. For instance, the understandability, engagement, and trust can be evaluated.

This study gives an overview of the current state of map design for a social topic and outlines the opportunities for map-makers. Maps can not only show the geographic locations of objects, but also an instrument to synthesize computer calculation functions and human visual perception to contribute to collaborative thinking. This study shows that different maps should be deliberately created to suit different contexts. More data-intensive and highly interactive maps will be required in the future. As a result, it will become more challenging to ensure that map users can gain insights from data intuitively and effectively.

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Data availability statement

The sample maps collected in this study are openly available on Zenodo at https://doi.org/10.5281/zenodo.11620024.

References

Abdelfattah, L., Deponte, D., & Fossa, G. (2022). The 15-minute city: Interpreting the model to bring out urban resiliencies. *Transportation Research Procedia*, *60*, 330–337. New scenarios for safe mobility in urban areas. Proceedings of the XXV International Conference Living and Walking in Cities (LWC 2021), September 9–10, 2021, Brescia, Italy. https://doi.org/10.1016/j.trpro.2021.12.043

Akhter, S., Ahsan, N., Quaderi, S. J. S., Al Forhad, M. A., Sumit, S. H., & Rahman, M. R. (2020). A sumo based simulation framework for intelligent traffic management system. *Journal of Traffic and Logistics Engineering*, *8*(1), 1–5. https://doi.org/10.18178/jtle.8.1.1-5

Allen, J., & Farber, S. (2020). Planning transport for social inclusion: An accessibility-activity participation approach. *Transportation Research Part D: Transport and Environment*, *78*, Article 102212. https://doi.org/10.1016/j.trd.2019.102212

Bae, S. S., Zheng, C., West, M. E., Do, E. Y. -L., Huron, S., & Szafir, D. A. (2022). Making data tangible: A cross-disciplinary design space for data physicalization. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, CHI '22, New York, NY, USA. Association for Computing Machinery.

Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy*, *15*(2), 73–80. New Developments in Urban Transportation Planning. https://doi.org/10.1016/j.tranpol.2007.10.005

Büttner, B., Seisenberger, S., Larriva, M. T. B., De Gante, A. G. R., Haxhija, S., Ramirez, A., McCormick, B., & Atanova, A. (2022). *Urban mobility next 9: ±15-minute city: Human-centred planning in action mobility for more liveable urban spaces*. Accessed: November 09, 2023, from https://www.eiturbanmobility.eu/wp-content/uploads/2022/11/EIT-UrbanMobilityNext9_15-min-City_144dpi.pdf.

Caka, F., Sokolo, Z., Gashi, M., & Milutinovic, D. (2021). *Sustainable urban mobility plan (sump) guidelines: Guidelines for developing and implementing a sump in kosovo's cities*. Accessed: November 17, 2023, from https://unhabitat.org/sites/default/files/2021/08/sump-guidelineseng.pdf.

de Sherbinin, A., Bukvic, A., Rohat, G., Gall, M., McCusker, B., Preston, B., Apotsos, A., Fish, C., Kienberger, S., Muhonda, P., Wilhelmi, O., Macharia, D., Shubert, W., Sliuzas, R., Tomaszewski, B., & Zhang, S. (2019). Climate vulnerability mapping: A systematic review and future prospects. *WIREs Climate Change*, *10*(5), e600. https://doi.org/10.1002/wcc.v10.5

Diao, M. (2019). Towards sustainable urban transport in singapore: Policy instruments and mobility trends. *Transport Policy*, *81*, 320–330. https://doi.org/10.1016/j.tranpol.2018.05.005

European Commission, E. (1992). Green paper on the impact of transport on the environment – a community strategy for 'sustainable mobility'. (p. 55).

Fabrikant, S. I., Christophe, S., Papastefanou, G., Lanini-Maggi, S., Xiao, N., M. -P. Kwan, & Lin, H. (2012). *Emotional response to map design aesthetics*.

Farella, E., Ferron, M., Giovanelli, D., Leonardi, C., Marconi, A., Massa, P., Murphy, A. L., Nori, M., Pistore, M., & Schiavo, G. (2020). *Discovering the world, through small green steps!*. Accessed: November 09, 2023, from https://kidsgogreen.eu/en/.

Fiore, S., Elia, D., Pires, C. E., Mestre, D. G., Cappiello, C., Vitali, M., Andrade, N., Braz, T., Lezzi, D., Moraes, R., Basso, T., Kozievitch, N. P., K. V. O. Fonseca, Antunes, N., Vieira, M., Palazzo, C., Blanquer, I., Meira, W., & Aloisio, G. (2019). An integrated big and fast data analytics platform for smart urban transportation management. *IEEE Access*, *7*, 117652–117677. https://doi.org/10.1109/Access.6287639

Fish, C. S., & Calvert, K. (2017). An analysis of interactive solar energy web maps for urban energy sustainability. *Cartographic Perspectives*, *2016*(85), 5–22. https://doi.org/10.14714/CP85.1372
Forsythe, A., Nadal, M., Sheehy, N., Cela-Conde, C. J., & Sawey, M. (2011). Predicting beauty: Fractal dimension and visual complexity in art. *British Journal of Psychology*, *102*(1), 49–70. https://doi.org/10.1348/000712610X498958
Gartner, G. (2019). Functional cartography – about the quality of maps from the era of artefacts to the era of services and beyond. *Abstracts of the ICA*, *1*, 88.
Heimerman, A. (2022). *Regio it and staex are building a prototype for a smart city dashboard*. Accessed: November 09, 2023, from https://staex.io/smart-city-staex-regioit.
Ibeas, A., dell'Olio, L., & Montequín, R. B. (2011). Citizen involvement in promoting sustainable mobility. *Journal of Transport Geography*, *19*(4), 475–487. https://doi.org/10.1016/j.jtrangeo.2010.01.005
Joost Adorf, J. S. (2022). *Digital twin solution for cycling policy*. Accessed: November 14, 2023, from https://www.argaleo.com/en/oplossingen/fietsbeleid/.
Kent, A. J., & Vujakovic, P. (2011). Cartographic language: Towards a new paradigm for understanding stylistic diversity in topographic maps. *The Cartographic Journal*, *48*(1), 21–40. https://doi.org/10.1179/1743277411Y.0000000004
Krippendorff, K. (2004). Measuring the reliability of qualitative text analysis data. *Quality and Quantity*, *38*(6), 787–800. https://doi.org/10.1007/s11135-004-8107-7
Lakhal, S., Darmon, A., Bouchaud, J.-P., & Benzaquen, M. (2020). Beauty and structural complexity. *Physical Review Research*, *2*(2), Article 022058. https://doi.org/10.1103/PhysRevResearch.2.022058
LIDA (2020). *How data providers and analysts can utilize connected car data*. Accessed: November 14, 2023, from https://xyzt.ai/2020/12/01/become-a-traffic-data-rockstar/.
Liu, X., Huang, Y., Xu, X., Li, X., Li, X., Ciais, P., Lin, P., Gong, K., Ziegler, A. D., Chen, A., Gong, P., Chen, J., Hu, G., Chen, Y., Wang, S., Wu, Q., Huang, K., Estes, L., & Zeng, Z. (2020). High-spatiotemporal-resolution mapping of global urban change from 1985 to 2015. *Nature Sustainability*, *3*(7), 564–570. https://doi.org/10.1038/s41893-020-0521-x
MacEachren, A. M. (1994). Visualization in modern cartography: Setting the agenda. *Visualization in Modern Cartography*, *28*(1), 1–12.
Macinnes, L., & Doran, K. (2020). *Vcity mobility plan 2021 – 2023*, edinburgh. Accessed: November 09, 2023, from https://www.edinburgh.gov.uk/downloads/file/29320/city-mobility-plan-2021-2030.
McCormack, J., Roberts, J. C., Bach, B., Freitas, C. D. S., Itoh, T., Hurter, C., & Marriott, K. (2018). Multisensory immersive analytics (pp. 57–94). Springer International Publishing.
Moriarty, S. E. (1997). A conceptual map of visual communication. *Journal of Visual Literacy*, *17*(2), 9–24. https://doi.org/10.1080/23796529.1997.11674518
Muehlenhaus, I. (2013). The design and composition of persuasive maps. *Cartography and Geographic Information Science*, *40*(5), 401–414. https://doi.org/10.1080/15230406.2013.783450
Mutlag, W. K., Ali, S. K., Aydam, Z. M., & Taher, B. H. (2020). Feature extraction methods: A review. *Journal of Physics: Conference Series*, *1591*(1), Article 012028.
Noll, B., Schmidt, T. S., & Steffen, B. (2022). Analyzing the competitiveness of low-carbon drive-technologies in road-freight: A total cost of ownership analysis in europe. *Applied Energy*, *306*, Article 118079. https://doi.org/10.1016/j.apenergy.2021.118079
Ortag, F. (2009). Variables of aesthetics in maps. In *Cartography and art* (pp. 1–9). Springer.
Pajares, E., Jehle, U., & Shkurti, M. (2021). *Plan sustainable cities and regions*. Accessed: November 16, 2023, from https://plan4better.de/en/tutorials/isochrone/.
Pánek, J. (2018). Emotional maps: Participatory crowdsourcing of citizens´ perceptions of their urban environment. *Cartographic Perspectives*, (91), 17–29.
Peterson, M. P., Gartner, G., & Fairbairn, D. (2023). Affordances and models of cartographic communication. *Abstracts of the ICA*, *6*, 198.
Pirlea, A. F., & Lambrechts, M.2023). *'sustainable transport for a livable future' in atlas of sustainable development goals 2023*. Accessed: November 09, 2023, from https://datatopics.worldbank.org/sdgatlas/goal-9-industry-innovation-and-infrastructure/?lang=en.
Ranasinghe, C., & Degbelo, A. (2023). Encoding variables, evaluation criteria, and evaluation methods for data physicalisations: A review. *Multimodal Technologies and Interaction*, *7*(7), 73. https://doi.org/10.3390/mti7070073

Riley, H. (2024). Visualcy: The progenitor of literacy and numeracy. *Journal of Visual Literacy*, *43*(1), 46–65. https://doi.org/10.1080/1051144X.2024.2315542

Rinne, J., Virtanen, J.-P., Sahala, S., Kostiainen, J., & Koskela, A. (2022). *Digital twin for mobility: Concept and baseline study working paper*. Accessed: November 14, 2023, from https://mobilitylab.hel.fi/app/uploads/2022/09/Digital-Twin-for-Mobilty.-Working-paper-version-9-September-2022.pdf.

Robinson, A. H., & Petchenik, B. B. (1975). The map as a communication system. *The Cartographic Journal*, *12*(1), 7–15. https://doi.org/10.1179/caj.1975.12.1.7

Schnur, S., Bektaş, K., & Çöltekin, A. (2018). Measured and perceived visual complexity: A comparative study among three online map providers. *Cartography and Geographic Information Science*, *45*(3), 238–254. https://doi.org/10.1080/15230406.2017.1323676

Shahraki, N., Cai, H., Turkay, M., & Xu, M. (2015). Optimal locations of electric public charging stations using real world vehicle travel patterns. *Transportation Research Part D: Transport and Environment*, *41*, 165–176. https://doi.org/10.1016/j.trd.2015.09.011

Shigeno, K., Borger, S., Gallo, D., Herrmann, R., Molinaro, M., Cardonha, C., Koch, F., & Avegliano, P. (2013). Citizen sensing for collaborative construction of accessibility maps. In *Proceedings of the 10th International Cross-Disciplinary Conference on Web Accessibility*, W4A '13, New York, NY, USA. Association for Computing Machinery.

SIMETRA (2022). *Ritm3 – effective solution for sustainable traffic management*. Accessed: November 15, 2023, from https://trafficinfratech.com/ritm3-effective-solution-for-sustainable-traffic-management/.

Steinmann, R., Krek, A., & Blaschke, T. (2005). Can online map-based applications improve citizen participation?. In M. Böhlen, J. Gamper, W. Polasek, & M. A. Wimmer, (Eds.), *E-Government: Towards electronic democracy* (pp. 25–35). Springer Berlin Heidelberg.

Stemler, S. (2000). An overview of content analysis. *Practical Assessment, Research, and Evaluation*, *7*(1), 17.

Urquijo, J. (2018). *Ciclogreen, the app that rewards sustainable transport*. Accessed: November 15, 2023, from https://www.greenappsandweb.com/en/android-en/rewarding-sustainable-mobility-solutions/.

Vartanian, O., & Chatterjee, A. (2022). 27The aesthetic triad. In *Brain, beauty, and art: Essays bringing neuroaesthetics into focus*. Oxford University Press.

Verena, K., Bogucka, P. E., Meng, L., & Krisp, M. J. (2023). How we see time – the evolution and current state of visualizations of temporal data. *International Journal of Cartography*, *9*(2), 392–409. https://doi.org/10.1080/23729333.2022.2156316

Vijverberg, A. (2019). *Revealing the city's rhythms in real time*. Accessed: November 15, 2023, from https://www.geodan.com/knowledge-and-innovation/managing-urban-processes-intelligently-with-the-amsterdam-smart-city-dashboard/.

Voi, T. (2021). *Voi launches impact dashboard for more sustainable transport choices*. Accessed: November 16, 2023, from https://futuretransport-news.com/voi-launches-impact-dashboard-for-more-sustainable-transport-choices/.

Yang, J., Jia, F., Xu, Y., Ding, L., & Liu, N. (2023). Building an open dataset of ubiquitous map images for cartographic research: Practices and prospects. *Abstracts of the ICA*, *6*, 281.

Yeon, H., Eom, T., Jang, K., & Yeo, J. (2023). Dtumos, digital twin for large-scale urban mobility operating system. *Scientific Reports*, *13*(1), 5154. https://doi.org/10.1038/s41598-023-32326-9

Zegras, C., Leape, J., Carrasco, J. A., Navas, C., Venter, C., & Vergel-Tovar, E. (2020). Scaling up innovative participatory design for public transportation planning: Lessons from experiments in the global south. *Transportation Research Record*, *2674*(12), 25–37. https://doi.org/10.1177/0361198120940998

Zheng, A., Wu, P., Xiao, F., Chen, X., Sun, Z., Fan, W., Li, L., & Cao, X. (2022). *Mobility as a service big data platform*. Accessed: November 14, 2023, from https://www.paircity.com/home.

Zhu, Q., Liu, Y., Liu, M., Zhang, S., Chen, G., & Meng, H. (2021). Intelligent planning and research on urban traffic congestion. *Future Internet*, *13*(11), 284. https://doi.org/10.3390/fi13110284